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FINAL REPORT

ON THE

DOE/NV/10503--T2

PATHWAY ANALYSIS TASK

SUBMITTED TO THE

U. S. DEPARTMENT OF ENERGY
NEVADA OPERATIONS OFFICE
LAS VEGAS, NV

CONTRACTS: DE-AS08-79NV10057
DE-AC08-86NV10503

BY

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APRIL 1993

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MEMORANDUM

TO: Bruce Church, Dave Wheeler, and JoAnne Burrows, DOE/NVOO
Lynn Anspaugh, LLNL

FROM: Ward Whicker and Tom Kirchner, CSU

SUBJECT: Final Report, Pathway Analysis Task

DATE: 26 April 1993

At long last, here is the final report of the Pathway Task. We will be happy to modify the report per your suggestions if you have any. The part of the report that you have not seen before, namely the internal dose estimates, should be reviewed fairly carefully, since this is the basic punch line of the report. There are many different ways to summarize the massive data files on internal doses. We hope we have chosen some of the more obvious ones that make sense. If you think of something important that we overlooked, please let us know.

The next task is to finish the lifestyle survey report. We have included some of the survey data in the enclosed final report as an appendix. This is not completely comprehensive however, so there is still a need to have such a report on the survey. We've had some discussions with Carol Thompson on how best to proceed. Ward has agreed to provide most of the narrative on why and how the survey was done, as well as how the results were used. Carol will provide the statistical summaries. We are not sure how long this particular effort might take.

FWW:jb
Enclosure

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APRIL 1993

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INTRODUCTION

The Pathway Analysis Task constituted one of several multi-laboratory efforts to estimate radiation doses to people, considering all important pathways of exposure, from the testing of nuclear devices at the Nevada Test Site (NTS). This overall project, known as the Offsite Radiation Exposure Review Project (ORERP), was initiated in 1979 and supported by the Nevada Operations Office of the U.S. Department of Energy (Church, et al., 1990). The primary goal of the Pathway Analysis Task was to predict radionuclide ingestion by residents of Utah, Nevada, and portions of seven other adjoining western states following radioactive fallout deposition from individual events at the NTS. The estimated quantities of 21 of the most significant radionuclides ingested were converted to internal organ dose estimates using age- and organ-specific dose factors compiled by the internal dose task group of the Lawrence Livermore National Laboratory (Ng, et al., 1990).

The events leading up to the establishment of the ORERP are well-documented in Church, et al. (1990). In brief, from 1951 through 1962, approximately 100 above-ground nuclear tests occurred at the NTS. Some of the resulting fallout patterns encompassed inhabited areas of the region. These included rural residences, farms, towns and larger cities. Although human radiation exposures were, in general, considered "low" and of little if any health concern, the precise magnitude and uncertainty in these exposures were not well-established prior to ORERP. The publication of one particular epidemiological study (Lyon, et al., 1979), implied a causal relationship between fallout radioactivity and childhood leukemia. This and other publications (many from the popular press) helped to raise public concern and political attention. One manifestation of this was a large lawsuit; namely,

Allen vs. United States (Civil Action No. C-79-515, U.S. District Court for the District of Utah Central Division, filed August 30, 1979). These and other related events and concerns prompted the need for a thorough re-evaluation of radiation exposures to the public from fallout produced by nuclear detonations at the NTS.

The goal of ORERP was to produce new dose estimates (with expression of their uncertainties), from all important modes of exposure, using actual field measurements of ground-level radiation exposure rates as the starting point of the calculations and the best-available information and technology that could be obtained to complete the dose estimates. An exceptional degree of independent peer-review was provided throughout the study by the Dose Assessment Advisory Group (DAAG) (Church, et al., 1990) and others representing a broad spectrum of science and society. This continual technical review, combined with long-term and uninterrupted support for the project, provided the opportunity to approach the best estimates of doses humanly possibly, as well as numerous advances in the art and science of environmental dose reconstruction.

This report provides comprehensive documentation of the activities and accomplishments of Colorado State University's Pathway Analysis Task during the entire period of support (1979-91). The history of the project will be summarized, indicating the principal dates and milestones, personnel involved, subcontractors, and budget information. Accomplishments, both primary and auxiliary, will be summarized with general results rather than technical details being emphasized. This will also serve as a guide to the reports and open literature publications produced, where the methodological details and specific results are documented. Selected examples of results on internal

dose estimates are provided in this report because the data have not been published elsewhere. A complete list of all publications and reports produced is provided.

PROJECT HISTORY

Key Personnel

The Pathway Analysis Task formally began its work September 1, 1979 through the establishment of Contract DE-AS08-79NV10057 between the U.S. Department of Energy, Nevada Operations Office (DOE/NV00), and Colorado State University (CSU). F. Ward Whicker, Department of Radiological Health Sciences, has served as the principal investigator throughout the history of the project, except for the final year. In December 1982, Thomas B. Kirchner became a co-principal investigator and has since shared many administrative and leadership duties with Ward Whicker. Starting in February 1991, F. W. Whicker spent 22 months at the Savannah River Ecology Laboratory (SREL), in Aiken, South Carolina and Tom Kirchner became the sole principal investigator to enable completion of the final dose estimates. This report was drafted by Ward Whicker while in residence at SREL and completed after his return to CSU in December 1992.

From the outset of the project, the principal investigators were able to bring complementary knowledge and skills together to accomplish the task of pathway analysis. Ward Whicker's cumulative experience in radionuclide transport processes was combined with Tom Kirchner's skills in writing complex computer codes that simulate coupled processes in natural or managed ecosystems. Without a strong technical base and commitment in either area, the project would have failed. A number of other areas were also crucial to the success of the project. One was the development of a comprehensive data base on agricultural practices throughout the geographic region of interest. This was accomplished under the leadership of Dr. Gerald M. Ward, Professor of

Animal Sciences at CSU. Dr. Ward guided efforts of subcontractors from Utah State University and the University of Nevada, Reno who assisted in the task of agricultural data procurement. He also gathered much of this type of information personally.

Two CSU graduate students, namely, David D. Breshears and Mark D. Otis also played crucial roles in the project, particularly in the areas of model uncertainty and sensitivity analysis. Working under the guidance of the principal investigators, they produced a significant degree of understanding of the uncertainty of the PATHWAY model's predictions and of those parameters which dominate the results and their uncertainties. During the latter phases of the project, Dave Breshears was extremely active in our efforts to test PATHWAY predictions against data sets resulting from the Chernobyl accident in the Soviet Union. This was accomplished under the auspices of an international model validation study called BIOMOVs.

A large number of other individuals at CSU contributed importantly to various aspects of the project. In the early stages of the project, A. William Alldredge, Professor of Fishery and Wildlife Biology, CSU, investigated the potential importance of mule deer and other wildlife species in the diets of people in the primary study areas. C. Richard Tracy, Professor of Zoology, CSU, helped with the development of a factorial analysis of the relative importance of PATHWAY model parameters and their interactions. Shawki A. Ibrahim, Associate Professor of Radiological Health Sciences, CSU, investigated observed variability of radionuclide concentrations in human tissues in an attempt to verify the reasonableness of the variance predictions of the stochastic version of the PATHWAY model. Tracy Ikenberry researched numerous foodchain transport parameters as a requirement for his M.S. thesis

at CSU, many of which were adopted in the PATHWAY model. W. John Smith, after completing his Ph.D. requirements at CSU, provided a critical evaluation of the resuspension process, one of the more influential parameters in the PATHWAY model. Diane Reichert and Diane Clarke, students in Animal Science at CSU, provided help to Gerry Ward and contributed to the agricultural practices data base. Susan Tench, a M.S. candidate at CSU studied ^{137}Cs in the sediment layers of Utah lakes and reservoirs in an effort to understand regional histories of fallout deposition. Jeffrey J. Whicker, Los Alamos National Laboratory, helped complete the analysis and writeup of the sediment study. April D. Whicker compiled many of the data sets used in the PATHWAY model validation exercises. Joann Brown provided outstanding secretarial services throughout the history of the project.

A number of colleagues from other organizations provided helpful critique, technical advice and, in some cases, essential collaboration. Carol Thompson and Forest Miller of the Desert Research Institute, Las Vegas, NV, provided essential assistance in the design and analysis of a 10-county survey of public food habits and lifestyles. This information constituted one of several data bases needed in the internal organ dose computations. Among our colleagues who provided critical examination of and suggestions for the PATHWAY model during its development were F. Owen Hoffman and Laura McDowell-Boyer, Oak Ridge National Laboratory; Yook C. Ng and Lynn R. Anspaugh, Lawrence Livermore National Laboratory; M. E. Wrenn and H. A. Hawthorne, University of Utah; R. Gene Schreckhise, Pacific Northwest Laboratories; and Steven L. Simon, University of North Carolina, presently with the Nuclear Claims Tribunal, Majuro, Marshall Islands. Members of the Dose Assessment Advisory Group, which provided periodic review and critique of ORERP, aided

the quality of our product significantly. Those whom were particularly interested in the pathway analysis task included E. L. Alpen, J. A. Auxier, W. J. Breed, G. G. Caldwell, R. D. Miercort, R. O. McClellan, and M. E. Wrenn.

Subcontracts were let to several organizations to provide information, assistance and critique. The first was to Dixie College in October 1980 to provide a regional survey of lifestyles, food habits and private agricultural practices. H. Loraine Woodbury served as the principal investigator for Dixie College. The second subcontract, initiated in March 1983, was to the University of Nevada, Reno for a study of the milk distribution system in Nevada. James R. Garrett served as the principal investigator. The third subcontract, let to Utah State University in November 1984, concerned dairy production and pasture utilization by dairy cows in Utah. This work was performed by J. L. Walters, R. D. Plowman, C. H. Mickelsen and N. L. Zaugg. A fourth subcontract was provided to the Union Carbide Corporation, prime contractor for Oak Ridge National Laboratory in July 1983. This provided for the in-residence services of Dr. F. Owen Hoffman to provide a critical review of PATHWAY. A fifth subcontract was let to John Heasley in January 1984 to provide programming assistance to Tom Kirchner.

From the outset of the program to the completion of the project, the pathway analysis task group received unfailing support, encouragement and patience from Bruce W. Church, David L. Wheeler, and their coworkers representing the sponsor, the Nevada Operations Office of the U.S. Department of Energy. We also received continual encouragement and outstanding scientific leadership from ORERP's Scientific Director, Lynn R. Anspaugh. All of these individuals realized that the ORERP produced much more than dose estimates; it also provided significant advancements in the art and science of

dose reconstruction. This required far more time and resources than was initially envisioned. Had it not been for the patience and dedication to see the project through, the entire effort might have been judged, in the final assessment, a failure.

Project Evolution and Milestones

The first and most obvious job of the Pathway Analysis Task was to develop a conceptual model of radionuclide transport in agricultural ecosystems, including the ultimate transport to people through ingestion pathways. The second task was to efficiently encode the model to enable the many tens of thousands of individual calculations envisioned to be run by computer. It was realized early on that although numerous foodchain transport models had been developed, none could be directly applied to the special requirements of this task. These special requirements included the need for a dynamic, realistic, flexible, testable, and scientifically defensible model that in addition to producing single estimates, could also produce uncertainty distributions using Monte Carlo (random sampling) approaches to error propagation. The model would be required to handle different types of agricultural ecosystems, a large number of radionuclides, discrete fallout events, seasonal phenomena, different geographic ²regions, complex milk distribution systems, different lifestyles, ages, and food habits, etc. These requirements essentially dictated a model developed from scratch, but one that could build on known processes, parameters, and available computational tools. From the outset, we sought critical peer review, both from the Dose Assessment Advisory Group and from independent experts.

The conceptual and computational framework for the model, which we termed "PATHWAY," was completed rather early in the project. For example, by December 1980, we had developed the fifth version of PATHWAY and were already in the process of comparing model predictions with real, independent sets of observed data. From that point on, the basic structure of the model has not changed a great deal. However, many minor refinements were added over the next 10 years as our knowledge grew. One of the more daunting tasks was that of describing model uncertainties and properly propagating errors with due attention to additive and multiplicative processes and parameter correlations. This effort was begun during the first year of the project; however, it required several years to find data on the experimental distributions of the various parameters and to provide justification for their application to our situation. In the early years of the project, we essentially proceeded with assumptions of independence for the parameters. During the later part of the 1980's however, it became apparent that by summing doses across radionuclides, we were forcing many correlations and this had to be dealt with computationally. A procedure was worked out for the problem, but it required a great deal of time and effort.

Final documentation of the computational codes was completed and delivered to ORERP in January 1992 (Kirchner, 1992). These codes consisted of the agricultural, pathway, and human ingestion models that interface for actual computations.

Toward the latter stages of the project, the illness of Yook Ng of Lawrence Livermore National Laboratory (LLNL) led to the need for CSU to handle the internal dose computations. This was to have originally been performed by LLNL. Our task changed from one of providing intakes per unit

deposition to one of providing dose estimates by fallout event, geographic location, age, sex, organ and radionuclide. This required use of the Town Data Base, compiled by the Desert Research Institute (DRI) to estimate time-normalized radiation exposure rates (by event, location), the conversion to radionuclide-specific deposition (Hicks, 1982), the calculation of radionuclide intakes (by radionuclide, sex, age, event, location), and then the calculation of dose (by radionuclide, sex, age, organ, event, location). The accession of several data bases and proper coding and data base interfacing for the calculations, along with estimation of the inherent uncertainties, turned out to be more complex than originally anticipated and required 2-3 years. The first set of dose results for non-specified individuals that had been verified and spot-checked to our satisfaction were delivered to ORERP in rough form in July 1990 and in more complete and accurate form in April 1991. The collective dose results by community (town) across events and by event across communities were completed January 22, 1992 (Kirchner and Whicker, 1992).

The development of the appropriate data bases for the Pathway Analysis Task required a great deal of time and effort from late 1980 through 1987. The process of gaining approval to conduct a public survey of life styles, food habits, and private agricultural practices involved permission of the U.S. Department of Energy as well as the U.S. Office of Management and Budgets (OMB). A specific survey design and questionnaire was proposed and these went through several iterations before approval was granted by OMB. This process required approximately 18 months and involved substantial paperwork. When the survey was finally initiated, the assistance of local college students was acquired to do the actual survey. The initial survey was confined to three

counties: Iron and Washington in Utah and Lincoln in Nevada. Later, the geographic scope of ORERP was increased and, as a result, it became necessary to enlarge the coverage of the lifestyle survey to a total of 10 counties in Nevada, Utah and Arizona. The Desert Research Institute took a lead role in the extended survey and in tabulating results of the survey.

As previously mentioned, compilation of the data bases on agricultural practices and milk distribution patterns was achieved by Gerry Ward with the assistance of two subcontractors (University of Nevada, Reno and Utah State University), as well as graduate students. This work began in 1981 and essentially culminated in 1987 with a summary report (Ward and Whicker, 1987), and later, a publication (Ward and Whicker, 1990). The computer-accessible version of the milk distribution data base was delivered to ORERP in April 1991. This work considered geographic variations in various agricultural statistics for Utah, Nevada, and portions of California, Oregon, Idaho, Wyoming, Colorado, New Mexico and Arizona. This study area encompassed the Phase I and Phase II regions defined by the ORERP. The principal agricultural statistics compiled were sources, distributors and consumers of milk, pasture use, hay cutting dates, feed intake, and milk delay times between production and consumption. As with other tasks, this one took much longer to complete than expected, primarily because of the enlarged geographic scope.

During the last 3-4 years of the project, we became fairly heavily involved in BIOMOVs, an international study sponsored primarily by the Swedish government to compare and test the predictive accuracy of foodchain transport models. We viewed this involvement as a good opportunity to test the global applicability of the PATHWAY model and to gain additional insights and a broadened perspective. Numerous working meetings were held throughout the

northern hemisphere and members of our group (Whicker, Kirchner and Breshears) were able to attend most of these. We were specifically involved in the A-4 Scenario in which data sets following the Chernobyl accident from many locations in the northern hemisphere were made available for comparison to the predictions of models from numerous countries. Measured concentrations of ^{131}I and ^{137}Cs in air were provided to the modelers, who then produced estimates of time-dependent concentrations in forage, meat, and milk. Then, the measured concentrations in these materials were provided for comparison. This was found to be a very good learning experience for the modelers. Another contribution we made to BIOMOVs was to prepare a document on the relative importance of ingestion for multiple pathway assessments (Whicker, 1990), and a document concerning model reliability (Kirchner, 1991).

As an ORERP entity, our project required a great deal of communication and coordination throughout its history. For example, we attended approximately 37 task leaders' meetings and workshops or 3-4 such meetings per year. These meetings were primarily used to coordinate activities, communicate preliminary findings, and to encourage critical internal review and quality assurance. Some were also used to prepare for DAAG reviews or testimony. Written and oral progress reports were delivered by our task group at these meetings. We prepared 38 such reports, which provide a comprehensive record for documentation purposes of our progress, roughly on a quarterly basis. Supplementary addendums (7) and exhibits (4) were prepared in addition to the progress reports, usually in connection with DAAG reviews and testimony. Our complete set of progress reports and supplementary materials is provided as an appendix to this report.

In addition to the task leaders' meetings, we attended 11 DAAG reviews, 2 legal testimonies (including the Allen trial in Salt Lake City), 5 BIOMOVs meetings, 7 national/international meetings to formally present our project work, and 8 other meetings connected with the project. Thus, the total travel effort amounted to approximately 70 trips. The travel, while very important to the success of the project, consumed a great deal of time, perhaps on the order of 700 person-days, or nearly 3 person years, including time for preparation and post-trip catchup activities.

Contract and Budget Information

The initial contract between DOE/NV00 and CSU, (Contract DE-AS08-79NV10057), formally began September 1, 1979. This contract was terminated December 31, 1985. During that period, the total cumulative contract value was \$1,490,588 including direct and indirect costs. The project was continued under Contract DE-AC08-86NV10503 on February 7, 1986 and it ended on February 5, 1992. The total cumulative contract value for the latter period was \$976,751 including direct and indirect costs. For the entire 12.3 year period therefore, the total cost was \$2,467,339, or an average of \$205,612 per year. The spending rate of the program was not constant, however. The highest spending occurred during the mid-years of the program; the least occurred during the last few years. The expenditure rates over the history of the contracts were tied most closely to person years of effort, and secondarily to travel and computer time and/or hardware procurement.

Five significant subcontracts were let to other persons or organizations to assist our effort. These were all let during the period of our first

DOE/NV00 contract, DE-AS08-79NV10057. The pertinent information on these subcontracts is provided as follows:

- Dixie College, Lifestyle Survey
(10/01/80-09/30/81) \$15,288
- University Nevada, Reno, Milk Distribution
(03/01/83-01/17/84) \$15,676
- Union Carbide Corp., Model Review
(07/15/83-08/15/83) \$ 4,448
- John Heasley, Computer Programming
(01/01/84-03/31/85) \$28,490
- Utah State University, Dairy Practices
(11/01/84-02/01/85) \$14,761

PRIMARY ACCOMPLISHMENTS

In this section we highlight those accomplishments that were the primary responsibility of the Pathway Analysis Task. The level of detail is only comparable to an executive summary; however we provide reference to those publications within which the technical details are provided. The principal responsibilities of our task included the development and analysis of the PATHWAY model; the development of data bases on agricultural practices, milk distribution networks and food habits of people; and the production of internal dose estimates from ingestion pathways.

Development of the PATHWAY Model

We feel that the PATHWAY model is one of a very few state-of-the-art foodchain transport models in the world today. Its primary strengths are that it is dynamic, realistic, process-oriented, highly flexible, and easily testable. Its primary limitation is that it is parameterized only for the conditions of the arid and semi-arid parts of the western U.S. in the period of the 1950s. It could, with further effort, be parameterized for other regions and time periods. Our goals in developing PATHWAY were to achieve predictions as realistic and accurate as our knowledge and information would permit, with a full exposition of the magnitude of the uncertainty inherent in all predictions. The model's predictions have been compared to approximately 60 sets of independent, time-series data in order to test the accuracy of predictions. Using sensitivity analysis techniques, we have examined and ranked the primary sources of uncertainty in the model. The basic structure of PATHWAY, as well as a complete description of the processes simulated and

the parameters used is provided in Whicker and Kirchner (1987). This paper provides typical values for time-integrated concentrations per unit deposition of selected radionuclides in certain food products as a function of calendar date. It also provides typical estimates for time-integrated intakes by people per unit fallout deposition for selected radionuclides, dates (time of year), etc.

In a second major paper, we provided a general overview of the PATHWAY model, including its utility for making radionuclide ingestion estimates, and its general properties, including uncertainty, parameter sensitivity, and predictive accuracy (Whicker, et al., 1990). In this paper, the list of radionuclides simulated was increased to 21, and more refined diets, based on more information, were provided for dairy cows. The data requirements for running the model are described, as well as the various types of operating modes and output options. This paper also describes some of the differences between PATHWAY and several well-known steady state models, and contrasts some selected results from the different models.

We feel that one way in which PATHWAY is more advanced than many earlier models is the addition of new exposure pathways. For example, resuspension, which is a potentially significant process soon after fallout deposition, and particularly in arid climates, is handled in the model. In addition, soil ingestion, both by grazing animals and by people, is included. Again, under certain circumstances this ingestion process may be comparatively influential.

A second advancement in PATHWAY is the incorporation of seasonally dynamic processes. These include, for example, changes in the diets of cows through the growing season. This is extremely important because the difference in milk or meat concentrations of some radionuclides, especially

short-lived ones, can be great, depending on whether or not the cow is consuming fresh pasture. We also model the light- and temperature-dependent growth of plants, as well as their consumption, harvest, and senescence. These processes all affect the biomass, which in turn affects foliar interception, weathering, dilution, etc. The storage of harvested hay and grain, with allowance for radioactive decay during storage, is handled with up to 5 harvests/year for 2 years being tracked.

Another effort that has seldom been attempted in other models is that of dealing with food distribution networks, especially in the case of milk, which is an important source for ^{131}I , ^{137}Cs , and ^{90}Sr . We developed sufficient information on milk distribution patterns in the study region to consider the blending of milk produced in different areas where the cows and their feeds were exposed to differing amounts of fallout deposition. Differences in milk transit times from production to consumption were also considered, because this was important in the case of radionuclides with half lives on the order of 15 days or less. We also developed the capability of dealing with cattle feeds such as hay that might have been imported from another region. In general, however, most cattle feeds were grown and used locally. Human foods that were imported from geographic regions not impacted by NTS fallout, or that were bottled, canned or frozen at earlier times, were handled in the PATHWAY model by making appropriate adjustments to the ingestion rates of the various food items.

The PATHWAY model simultaneously simulated three different types of land management units, namely rangeland-grazing, human food crops, and pasture/hay systems. Such land management units have compartments representing quantities or concentrations of radionuclides in products such as fruits, leafy-

vegetables, other vegetables, grains, grain plants for silage, grass, hay or pasture, alfalfa, meats (beef, lamb and poultry), milk, milk products (cheese, cottage cheese, ice cream), and eggs. Other substances, such as fish and water were shown to be unimportant as radionuclide vectors to man during the 1950's in the study region, so they were not modelled.

Since the PATHWAY model operates numerically on daily time steps, various types of discrete events such as fallout deposition, diet changes, tillage, harvest, etc. can be scheduled. This makes the model extremely flexible, and as a fringe benefit, highly testable. For example, in comparing model predictions to real data sets, it turned out to be essential that the actual contamination scenario, agricultural conditions, management changes, etc. be simulated in the model. In addition, flexible output options such as daily inventories, concentrations, time-integrated concentrations, etc. enhance the testability of the model. Many models simply lack the detail and flexibility to enable critical comparisons with observed data sets.

In summary, we are proud of the PATHWAY model, its capabilities, and its tested performance. On the other hand, it is important to realize that the model, as presently structured and parameterized, has temporal and geographic limitations, and we do not advocate its blind application to any fallout deposition scenarios. Its use can only be made with a great deal of understanding of the model, the system being simulated, and the specific scenario conditions.

Analysis of the PATHWAY Model

The PATHWAY model was analyzed during and after its development so that four somewhat separate issues could be examined, namely verification and face

validity, overall accuracy of prediction, uncertainty of model predictions, and sensitivity of model predictions to various processes and parameter values. These areas of endeavor were necessitated by our goal of developing completely objective, best-estimates of dose, with free exposition of uncertainties, characteristics, strengths, and weaknesses of the model and its predictions. A brief overview of the results of these model analyses is given below.

Verification and Face Validity

Verification and face validity of a computational model concern verification of the computational scheme and code (programming), checking the accuracy of assumptions, and subjecting the model to critical peer review. Verification is pursued to assure that the code performs as intended without unintentional errors in programming, parameter value assumptions, transcription error, improper unit conversions, etc. Face validity is necessary for general acceptance by peers, and ultimately by users of the model results. We took these matters very seriously and devoted a great deal of time and effort to model verification and face validity.

The process of basic model verification was conducted primarily by T. B. Kirchner and F. W. Whicker, who independently cross-checked and verified equations, computer coding, input data entries, intermediate computational coding, results, and final output results. Somewhat independent modelling by D. D. Breshears and M. D. Otis confirmed outputs. F. W. Whicker made numerous independent calculations both by hand using analytical equations and by the use of TIME ZERO™ software which uses numerical algorithms to solve differential equations. The latter computations required simplifications but, even so, such calculations nearly always agreed to within 10% or better of the

pathway code result. In cases where agreement did not occur, the discrepancy was found and, if necessary, corrected. Clearly, it was impossible to check the many hundreds of thousands of computer computations. The best we could do was to focus on the most important pathways, radionuclides, test events, and locations. A variety of computerized schemes for checking the reasonableness of the output data were performed, such as plotting the output dose as a function of primary parameters such as exposure rate at H+12 hours. Figure 1 provides an example where thyroid dose is plotted against exposure rate. Variations in dose at given exposure rates are explained by differences in things like time of year (event), and prevailing agricultural and/or lifestyle differences. Even though there is variation, it is explainable and the trends run as expected.

Face validity of the PATHWAY model was pursued by asking knowledgeable peers to critique the model, by periodic DAAG reviews, and by numerous presentations and peer-reviewed publications. This process was conducted throughout most of the life of the project. We believe that the PATHWAY model, largely because of its critical scrutiny, is quite highly regarded by most knowledgeable peers in the field.

Validation: Accuracy of Prediction

The initial efforts to test the predictive accuracy of the PATHWAY model were summarized in a publication by Kirchner and Whicker (1984). In this work, the overall accuracy and temporal dynamics of PATHWAY simulations were compared to 37 sets of observed data. The observed data were gathered in the western and southwestern U.S. following the Smallboy event at the Nevada Test Site and during the global fallout period 1957-1967. In addition, some data from the Windscale accident in England were compared. Measurements and

Figure 1. Adult (≥ 19 years) thyroid dose as a function of H + 12 hour survey meter reading. All test events and Phase I and II locations are included.

predictions included ^{131}I , ^{137}Cs , ^{90}Sr , and ^{140}Ba in milk, ^{137}Cs and ^{90}Sr in pasture and alfalfa, and ^{137}Cs in beef.

These initial model validation results indicated that PATHWAY seems to provide reasonably accurate predictions and dynamic results that follow observed temporal trends. Ratios of predicted values to observed data seldom exceeded a factor of 3-4 from unity and predictions for ^{131}I in milk (the major internal organ dose contributor and pathway) were usually within 20% of the observed data. Considering the uncertainties of predictions, sampling variability in the data, and incomplete knowledge about all relevant conditions affecting the real data, we believe that our results were generally satisfactory.

As part of the international model validation study "BIOMOVs," we had the opportunity to compare PATHWAY's predictions of ^{131}I and ^{137}Cs in forage and milk and ^{137}Cs in beef with post-Chernobyl data sets from many locations in the northern hemisphere. These efforts are described in detail in our progress reports dated 5/24/88, 9/7/88, 1/11/89 and 4/26/89; as well as in the Scenario A-4 report of BIOMOVs (Nielsen, et al., 1991). Despite the fact that PATHWAY was parameterized for conditions in the southwestern U.S., it performed overall as well or better than the 21 other models studied, based on (geometric) mean predicted to observed (P/O) ratios and GSD's for 12 sites (Table 1). Overall, the geometric mean P/O ratios ranged between 0.59 and 2.8 for PATHWAY, and its uncertainty in P/O values across sites was among the lowest of all models. Nevertheless, we found weaknesses in PATHWAY related to not treating wet deposition and using forage to milk transfer coefficients too high for Chernobyl fallout. Overall, the lessons learned from the BIOMOVs exercise were very useful, and the international recognition of our work was greatly enhanced.

Table 1. Predicted to observed ratios for various models, BIOMOVs Scenario A4 time-integrals; statistics across 12 sites.

Model	¹³¹ I in vegetation		¹³¹ I in milk		¹³⁷ Cs in vegetation		¹³⁷ Cs in milk	
	GM	GSD	GM	GSD	GM	GSD	GM	GSD
SS57-IAEA	4.28	2.1	28.03	3.9	3.20	3.1	7.44	4.4
SS57-ORNL	2.95	2.3	7.28	4.0	1.66	2.0	1.66	2.9
RIST	9.81	1.8	9.65	4.5	4.19	1.0	6.25	1.8
AIRDOS/EPA	4.22	2.6	10.60	4.6	1.83	2.2	1.14	3.3
FARMLAND	3.68	2.0	17.46	4.5	0.79	4.2	1.26	5.5
SIRATEC	1.29	1.9	11.93	3.3	0.73	4.1	1.40	5.1
ABG	2.74	1.9	18.44	3.7	0.88	2.1	2.84	2.6
CRRIS	2.09	2.0	5.53	3.6	3.45	3.5	2.22	3.5
DOSIM	1.71	2.1	10.54	4.6	0.72	3.8	1.29	4.7
SPADE2	1.66	2.0	3.74	3.3	0.15	2.8	0.60	3.6
ECOSYS	1.04	1.7	1.42	4.1	0.76	1.6	0.54	2.8
CHERPAC	0.58	3.0	2.74	5.0	1.62	6.6	4.11	9.8
BIOPATH	0.91	2.0	4.54	3.6				
PRYMA	0.85	2.0	2.47	5.3	0.55	1.9	0.80	3.7
CIRCLE	0.71	1.8	2.59	4.4	0.38	3.4	0.58	5.8
TERFOC	0.66	1.7	3.87	4.5	0.71	1.9	1.29	2.2
CHRONIC	0.66	1.7	2.73	4.7	0.71	1.9	2.28	2.2
BILTH	0.70	3.0	0.75	3.2	0.37	2.3	0.15	2.6
ENEA PAS	3.26	2.1	13.32	3.2	0.74	2.3	6.74	3.5
RAGTIME	0.61	2.0	0.73	4.4	0.91	1.6	0.89	3.2
FOOD	0.61	2.1	3.69	5.5				
PATHWAY	0.59	1.8	2.80	4.2	0.94	2.2	2.0	2.1

Uncertainty of Model Predictions

The modern trend in radiation dose assessment is away from conservative point estimates and toward best realistic estimates with expressions of uncertainty. Uncertainty in model predictions result from two fundamental problems, namely the lack of knowledge and natural variability inherent in virtually all environmental processes that control dose to individual organisms or people from releases of radioactivity. Natural variability cannot be controlled, although it can be measured. Lack of knowledge can be reduced through scientific research and experience, but knowledge can never be perfect.

We attempted to characterize the uncertainty of PATHWAY model predictions by propagating estimated uncertainties in individual parameters and processes through to the resulting uncertainty distributions of appropriate output parameters such as concentrations, integrated intakes, or dose. This was done with various techniques, although we relied most heavily on "Monte Carlo" or complete random sampling of parameter distributions, repeated many times, to produce distributions of output that could be mathematically characterized (Otis, 1983; Breshears, et al., 1989).

Perhaps the greatest challenge in conducting an uncertainty analysis is the development of probability distributions for individual parameter values. In some cases, numerous experimental values were available in the literature, making possible the objective mathematical fitting of a distribution function. In other cases, experimental data were too sparse for such a procedure and it was necessary to rely on expert judgment to characterize a distribution. Parameter distributions used included normal, log-normal, triangular, rectangular, truncated normal or log-normal and, in some cases, empirical.

It was found that the probability distributions for relevant PATHWAY output could typically be described as log-normal in shape (Otis, 1983; Whicker, et al., 1990). Log-normal distributions may be described with a geometric mean (GM) as the measure of central tendency and the geometric standard deviation (GSD) as the measure of dispersion or variability around the geometric mean.

The most relevant end result output from the PATHWAY model was the integrated radionuclide intake per unit deposition. This output represents an integration over time, as well as a summation across food items assumed in the diet. It was found that the GSD values for this output were primarily dependent on the time of year that fallout was deposited and on the half life range of the radionuclide. These GSD values, overall, ranged from about 1.7 to 2.7 and averaged about 2.0 (Breshears, et al., 1989). A GSD of 2.0 implies that 2/3 of the output values could be expected to fall within a factor of 2 of the GM. Some 95% of the output values could be expected to fall within a factor of $(2.0)^2$ or 4 of the GM.

In general, multiplicative terms having uncertainties tend to cause expansion of the GSD. On the other hand, additive terms tend to cause a reduction in the GSD, essentially because of a greater chance of compensating errors. In calculating organ doses, there are both multiplicative and additive calculations involved. The GSD values for dose to an unspecified adult living in St. George, Utah, from the seven test events impacting that area, for example, ranged, depending on organ, from 1.30 to 1.79. For organ doses to individuals, in general, the GSD values typically fell in the range of 1.3 to 2.0, although some were lower and some higher. Computations for collective doses tended to produce GSD values that were substantially lower

(i.e., 1.04 to 1.11 for Phase I and II) than for unspecified individual doses (Kirchner and Whicker, 1992). Collective dose calculations involve mean dose values and uncertainty of means tends to be lower than that of individuals. Furthermore, summations across events and locations tend to reduce the relative uncertainty.

Parameter Sensitivity Analysis

Our primary goal in conducting sensitivity analyses was to determine which parameters and processes were most important in terms of their influence on model outputs. This is useful because it allows researchers to set priorities in the allocation of time and effort for developing and improving the model. Secondly, sensitivity analysis provides valuable insights into the characteristics of a model and improved understanding of the real world systems being simulated. Parameter values can influence model output both by virtue of the functional importance of the process the parameter represents, and by the magnitude of uncertainty in the value used in a particular model run.

We used two primary techniques for sensitivity analysis. First, the Monte Carlo runs connected with the uncertainty analysis procedure provided the data necessary to calculate partial correlation coefficients or partial ranked correlation coefficients. To do this, the parameter input selections were treated as independent variables, while the output was treated as the dependent variable. Multiple regression was then used to calculate the partial correlation coefficients (PCC's). Ranks of the PCC values were then assumed to provide an index of the relative influence of each parameter. The second technique employed analysis of variance of data obtained from full-

factorial sampling of specified input parameter values (Breshears, et al., 1992).

Sensitivity of time-integrated concentrations of ^{131}I and ^{137}Cs in milk were estimated as a function of the time of year that fallout was deposited, as a function of time following a spring deposition, and as a function of methodological sampling design. Sampling designs based on the variance of the parameters produced similar rankings whereas sampling designs based on the nominal values produced different rankings (Breshears et al., 1992). The dominant parameters affecting time-integrated concentrations of ^{131}I in milk were the initial fraction of radionuclides deposited on vegetation (alpha), timing and amount of pasture consumption, and the production rate of milk. For time-integrated concentrations of ^{137}Cs in milk, resuspension was a dominant parameter while pasture use was less important.

Development of Supporting Data Bases

The procurement of data, specific to given locals, lifestyles, ages, etc., was required as essential input to the PATHWAY codes. The principal data needs fell in the categories of agricultural practices, milk distribution networks, and lifestyle practices. As the geographic scope of ORERP increased through the life of the project, the data base requirements magnified well beyond the scope of effort originally anticipated. In retrospect, we believe it was the data bases, more than any other factor, that prolonged completion of ORERP.

Agricultural Practices

Since the PATHWAY model was designed to simulate the transport of radionuclides through agroecosystems to people, it was essential to understand

key agricultural practices that affect such transport. Agricultural management practices are extremely complex and vary both spatially and temporally. We employed several methods to obtain relevant data, including library work, personal observations, formal and informal interviews, and subcontracting of work to regional experts. Some of the essential information needs were: kinds and sources of feeds for food-producing animals, amounts of pasture and other feeds used as a function of time of year, tilling and harvest schedules for crops and livestock feeds, storage schedules for different livestock feeds, use and shipment of locally-grown crops and animal products, typical cultivation and irrigation methods, use of open ranges by livestock, typical slaughter dates for livestock, etc. Dr. Gerald M. Ward of the Department of Animal Sciences at Colorado State University served as our primary expert on agricultural practices and he compiled most of the relevant information. Most of the agricultural practices information is summarized in Ward and Whicker (1987); Ward and Whicker (1990); Garrett (1984); and Walters, et al. (1985).

Milk Distribution Networks

It was expected early in the project that milk would be a primary source of ingestion of important radionuclides such as ^{131}I , ^{137}Cs , and ^{90}Sr . Particularly in the case of ^{131}I , milk is typically the overwhelmingly dominant vector of intake, with frequently over 80% due to this source (Whicker and Kirchner, 1987). Milk is particularly important for ^{131}I when cows are using fresh forage or very recently cut hay. Therefore, it was essential to understand the milk transport patterns and distribution network in the study region. For example, people living in an area receiving direct fallout deposition may get substantial or trivial radiation doses to the

thyroid, depending on whether they consume milk produced locally or at some distant area that did not receive fallout deposition. On the other hand, people living in an area receiving no fallout could receive a measurable dose to the thyroid from drinking milk produced in an area that did receive fallout.

In addition to the requirement of quantifying the sources of milk to specific communities, it was important to know whether each source of milk came from a specific location or whether it came from a processor that blended milk from many locations. Many of the larger commercial milk producers collected raw milk shipments from complex networks of geographically-spaced individual dairy farms. This milk was blended, processed, then shipped to commercial distribution centers. Many of the smaller commercial dairies had their own local herds and thus did not import raw milk from other areas. Private individual "backyard" dairy cows were the principal sources of milk to some families, particularly those living in the more rural areas.

In the case of short-lived radionuclides, including the 8-day half-lived ^{131}I , it was also important to estimate the time delay from production to consumption. Five day delays, for example, would allow some 35% of the ^{131}I to decay during this time interval. For even shorter-lived radionuclides (e.g. $^{133,135}\text{I}$), the time delay is even more influential in determining dose. Complicating this factor was the general increase in delay times for commercial milk after 1958 when large bulk tanks began to be employed for transport and storage.

Just as important as geographic source of milk was the question of whether the dairy cows were consuming stored feed (usually alfalfa or grass hay) as fresh pasture or recently cut green feed. In the case of stored feed,

there is usually ample time for the virtually complete decay of ^{131}I prior to its consumption. The maximal ^{131}I concentrations in milk arise from cows feeding on fresh, recently-contaminated forage.

These were the primary data needs under the heading of milk distribution networks. Few data of this type were available in publications and written records. Therefore we developed the data base mostly from interviews with knowledgeable people such as dairy farmers, dairy plant operators, agricultural extension agents, and faculty of agricultural colleges. The methods and findings are detailed in Ward and Whicker (1987, 1990). The computerized version of the data bases is presented in Kirchner, Ward, and Whicker (1992).

Lifestyle Survey

A public survey of lifestyles, food habits and agricultural practices of the 1950s was conducted in ten counties of southern Utah, southern Nevada, and northwestern Arizona. Three counties, Washington and Iron in Utah, and Lincoln in Nevada, were surveyed in 1981 by Dixie College at St. George, Utah. H. Loraine Woodbury of Dixie College was the principal investigator. Seven additional counties were surveyed by the Desert Research Institute in 1982-83. These counties were White Pine, Nye, Esmeralda, and Clark in Nevada, Kane in Utah, and Mohave and Coconino in Arizona.

The general purpose of the survey was to provide specific data and information that would guide construction of, and provide parameters for, the PATHWAY model. The most important information needed included foods utilized, sources of foods, and specific estimates of consumption rates, along with estimates of uncertainty in these parameters. Although nationwide statistics were available to estimate food consumption rates (Rupp, 1980), these

statistics were heavily biased toward urban populations. Furthermore, they were not specifically relevant to the 1950s time frame and estimates of uncertainty in the data were not available.

We were also interested in the ability to analyze the survey results in a manner that would provide food consumption rates as a function of variables such as geography, lifestyle (e.g. occupation, community size, etc.), age, and sex. Other relevant information that could be easily gathered during personal interviews included home construction, time spent outdoors, source of water, infant feeding practices, and private agricultural practices. Agricultural practices data of interest included crops grown, animals raised, alfalfa cutting dates, livestock feeding regimes, fate of harvested crops or animal products, etc. This latter information was only supplied by those surveyed that were involved in agriculture, but this was an important supplement to the other data gathered in the study.

Unofficial, preliminary interviews were conducted with 206 local residents in the communities of Parowan, Cedar City, and St. George, Utah, and Panaca/Pioche, Nevada, to guide the development of an interview questionnaire. A sampling methodology was also developed with the help of Dr. Forest Miller of the Desert Research Institute, Las Vegas, Nevada. Since this was a public survey, it was necessary to obtain official approval for the survey through the U.S. Department of Energy and the Office of Management and Budgets. The survey form, sampling methodology and interview procedure were approved in the fall of 1980, some 18 months following the application. The interview form, as well as the instruction booklet for conducting the interviews is provided in APPENDICES A and B.

The sampling procedure involved several steps. First, the location of each house was marked on a street map for each named community and along all rural roads in each county. The street maps for each named community were laid out and groups of ten adjacent houses were delineated and given a number. Approximately 20% of the groups of ten houses were randomly selected for interview. People in each house within a selected group were contacted to determine whether they were both willing and qualified to be interviewed. To qualify for an interview, the person contacted must have lived in one of the counties surveyed between 1951 and 1962. In rural areas, the attempt was made to contact each house to determine whether an interview could be set up. A report from Dixie College that covers sampling procedures, a summary of contacts and interviews in the initial three-county survey, and a summary of interviews and man-hours spent on the project is provided in APPENDIX C.

The actual person-to-person interviews were carried out primarily by local college students and young people that were from the immediate area. The interviews were strictly voluntary and our sampling procedures made no attempt to find out whether or not an interviewee might be involved in radiation litigation (e.g. the Allen case). The entire process was designed to be as objective as possible. Perhaps the primary source of uncertainty, and potential bias, resulted from the recollections of people back into the 1950s time period (20-30 years preceding the actual survey).

As to the results from the survey, some 910 individuals were formally interviewed. Of those individuals giving a specific age (841), most (74%) were 46-75 years of age at the time of the survey and 89% lived in named communities rather than on isolated farms or ranches. A preponderance (62%) of the respondents were female. The counties contributing the highest

proportions of respondents were Washington (29%), Iron (19%), White Pine (18%), and Lincoln (9%). Selected results of the survey are enumerated in APPENDIX D. These data were compiled and presented by Carol Thompson of the Desert Research Institute.

Some selected findings of particular interest include:

- Some 51% of respondents obtained milk from a privately-owned cow.
- Some 63% of respondents grew at least some of their own leafy vegetables.
- The primary source of milk for infants was formula or canned (38%); 22% were breast-fed and 14% used fresh cow's milk.
- The mean milk consumption by teens and adults was 6% and 73% higher, respectively, than the survey population described by Rupp (1980). In the case of children, milk consumption was 11% less than that estimated by the Rupp survey.
- Intake of cheese was higher but intake of ice cream was lower in the 10-county survey population than in the Rupp (1980) population.
- Eighty to ninety percent of the milk, eggs, and meat consumed by residents of Iron, Washington, and Lincoln Counties was locally produced.
- A large but seasonal local production of fruits and vegetables was noted in the survey population.

The survey data revealed rather clearly the types of foods which required explicit modeling, those which could be indirectly inferred, and those which could be disregarded. For example, the heavy use of cheeses and lamb influenced our decision to model these items specifically, rather than to

lump them in with other food categories. The very low consumption of fish from the local area provided additional rationale for not modeling this item explicitly. Drinking water in the region was obtained almost exclusively from wells, springs, or treated urban systems, according to the survey. Thus, the initial decision to disregard drinking water as a significant source of radionuclide intake was strengthened by the survey.

About 29% of those interviewed were involved with farming or ranching in the 1950s and thus were able to provide information on agricultural practices. These data provided a valuable supplement to the information gathered by Dr. Gerald Ward through selective interviews. Much of this information was used directly in the modeling efforts.

In summary, the lifestyle survey was a critical ingredient for the process leading to credible internal dose estimates. The specific data for the region enhanced our confidence that important pathways were not overlooked and that the ingestion pathways were adequately represented for the region, which in some ways were uniquely different than larger U.S. populations taken as a whole. Finally, the survey produced uncertainty distributions in food consumption which was necessary to estimate the overall uncertainty in organ doses. Means as well as outlying or unique individuals could be properly represented in the envelope of possible dose outcomes.

Internal Dose Estimates

General Approach

The primary goal of the pathway analysis task has been the development of the models and information to enable the prediction of ingestion of radionuclides from NTS fallout by people living within the geographic bounds

of the ORERP study. Estimates of integrated radionuclide intake per unit deposition (Bq per Bq/m^2) were developed as a function of time of year (test event), geographic location (agricultural practices), age, sex, lifestyle, and radionuclide. These estimates could be multiplied by event-, location-, and radionuclide-specific deposition (Bq/m^2) to yield total activity ingested (in Bq). Deposition was estimated from the survey meter data base values compiled by DRI (Thompson, 1990), in terms of mR/hr at $H+12$ hours, and the normalized deposition in Bq/m^2 per mR/hr (Ng et al., 1990; Hicks, 1982). The final step leading to dose involved the multiplication of total intake (Bq) by an age, sex, organ, and radionuclide specific dose factor (Gy/Bq or $\text{rad}/\mu\text{Ci}$) as outlined by Ng et al., (1990).

The final step to internal dose from ingestion was originally the responsibility of the Lawrence Livermore National Laboratories Internal Dose Task Group. The illness of Y. C. Ng during the final years of ORERP led to the need for the CSU team to carry out this step. It also became apparent that it would be most efficient for CSU to handle all the data bases necessary to complete the internal dose computations. This included the town data base (Thompson, 1990), the radionuclide specific normalized deposition data base, the three data bases needed for intake per unit deposition (namely the agricultural data base, PATHWAY results file and the human ingestion model files), and the dose factor data base compiled by Y. C. Ng. This turned out to be a very daunting effort because of the sheer size and complexity of these data bases. This final effort was carried out by T. B. Kirchner and his simultaneous orchestration of numerous Sun Computer work stations. As an illustration of the magnitude of this task, we ran 34,434 site/event/lifestyle/population or individual simulation combinations. Using 200 Monte

Carlo simulations per combination yielded 6,886,800 runs for each of 8 age/sex combinations and 20 radionuclides. Thus, the total number of doses computed, not including sums, was on the order of 1.1 billion values.

The dose computations were carried out in different ways to meet certain needs. For example, doses to unspecified individuals were computed in stochastic mode by community, event, lifestyle, organ and age group with parameter uncertainties representing those individuals within the population. Next, the same sorts of computations were carried out with parameter uncertainties representing those of the mean of the population. The latter uncertainties were smaller than those representing individuals because uncertainties of mean values are less than those of individuals. This concept is not unlike that of the sample standard deviation compared to the standard error of the mean in normal statistics. In addition to unspecified individual doses, collective doses were computed by community, event, lifestyle, organ, and age group. Collective doses were estimated as the dose to the average unspecified individual times the number of individuals, and thus carried the units of person-rads. The uncertainties used were those representing the population means. Details of the error propagation procedures are described for the collective dose estimates in Kirchner and Whicker (1992).

Organ Doses and Relevant Factors

One of the most basic findings from the internal dose calculations was that by far, the largest doses were received by the thyroid gland. An example of this is a set of results for unspecified individuals living in St. George, Utah at the time of event Harry (Table 2). For all age groups, doses to the thyroid exceeded those to most other tissues of the body by roughly two or

Table 2. Organ doses from ingestion for unspecified individuals living in St. George, Utah, resulting from event Harry (5/19/53). Rural lifestyle assumed. Uncertainty estimates reflect those for individuals within the population. Results for males and females are averaged.

Organ	Infant (0-12 mo)		Child (1-11 yr)		(Teen (12-18 yr)		Adult (≥ 19 yr)	
	Dose (mrad)	GSD	Dose (mrad)	GSD	Dose (mrad)	GSD	Dose (mrad)	GSD
Thyroid	83,500	2.4	39,600	2.1	17,100	2.3	5,080	1.9
Lower large intestine	2,500	1.7	1,680	1.6	544	1.5	499	1.6
Upper large intestine	879	1.7	600	1.6	220	1.5	199	1.5
Bone surface	757	1.8	198	1.6	183	1.7	108	1.6
Red bone marrow	458	1.9	148	1.7	111	1.7	89	1.6
Small intestine	206	1.6	155	1.5	73	1.6	72	1.6
Stomach wall	177	1.6	113	1.6	56	1.6	57	1.6
Total body	110	1.7	81	1.6	47	1.7	48	1.7
Liver	90	1.7	65	1.7	41	1.8	42	1.7
Kidney	87	1.8	63	1.7	40	1.8	41	1.8
Ovaries	66	1.7	60	1.6	39	1.7	41	1.7
Uterus	56	1.6	51	1.7	36	1.8	40	1.8
Bladder wall	54	1.7	49	1.7	35	1.8	38	1.8
Adrenals	51	1.7	46	1.8	34	1.9	38	1.8
Spleen	50	1.7	45	1.7	33	1.8	35	1.9
Muscle	50	1.7	43	1.7	31	1.9	34	1.8
Pancreas	49	1.7	44	1.7	32	1.8	35	1.8
Testes	47	1.7	42	1.8	32	1.9	35	1.9
Lungs	47	1.7	41	1.7	30	1.8	33	1.8
Breast	44	1.7	37	1.7	28	1.9	30	1.9
Brain	44	1.7	37	1.7	27	1.8	29	1.9
Skin	40	1.7	34	1.7	25	1.8	27	1.8

three orders of magnitude. Next to the thyroid, the highest doses were received by the lower and upper large intestine, which receive significant beta and gamma radiation from the relatively insoluble radionuclides which pass essentially unabsorbed through the gastrointestinal tract. The thyroid doses were strongly age-dependent, with infants and children receiving the highest doses due to an enhanced dose factor for infants and high milk consumption by children.

The uncertainties in internal dose, represented by the GSD, ranged from about 1.5 to 2.4, with the highest uncertainties associated with thyroid doses. This can be explained on the basis that thyroid doses are primarily driven by ^{131}I intake, most of which is normally derived from milk consumption (Table 3). There is considerable uncertainty in ^{131}I concentrations in milk following events conducted at the time of year corresponding to that of the Harry Event (5/19/53), due to uncertainty as to whether cows are on pasture or not and in parameters affecting concentrations in pasture (Breshears, et al., 1989). There are also relatively large uncertainties in the amount and source of milk consumed by people (APPENDIX D).

In addition to providing insight about the relatively large uncertainties in thyroid dose, Table 3 reveals that the relative importance of various dietary items for radioiodine intake varies with the fallout event. For example, fallout from event Annie (3/17/53) occurred in early spring when little fresh pasture was available, thus milk was not the major source of radioiodine. Milk and milk products were relatively more important for event

Table 3. Relative contribution (%) of different food types to thyroid doses to unspecified males in St. George Utah.

Food Type	Event Harry (5/19/53)				Event Annie (3/17/53)			
	Age Group (years)				Age Group (years)			
	< 1	1-11	12-18	≥ 19	< 1	1-11	12-18	≥ 19
Milk	73	63	55	40	55	40	30	22
Milk Products	17	12	4	5	13	8	2	3
Cottage Cheese	--	--	8	21	--	--	4	12
Hard Cheese	--	--	--	--	--	--	--	--
Eggs	7	12	23	20	22	32	50	45
Leafy Vegetables	< 1	7	6	9	< 1	5	4	5
Other Vegetables	2	2	2	2	6	7	5	6
Grains	--	--	--	--	--	--	--	--
Meats	< 1	1	1	2	1	3	3	5
Soil	1	2	1	1	3	4	2	1

Harry since it occurred in mid-May as cows were mostly going onto fresh pasture at that time. Milk becomes even more important in summer, when pasture usage is at its maximum. Eggs, milk products that are consumed within a week or two of milk production, and leafy vegetables can be significant contributors as well to thyroid dose, depending on time of year, dietary patterns, age, and other factors. Hard cheese, meats, grains, and soil are generally insignificant sources of radioiodine intake.

As mentioned before, ^{131}I dominated the dose to the thyroid. Even though ^{131}I represents a very small fraction (a few percent) of the total radioactivity initially deposited in weapons test fallout (Figure 2), it typically contributes well over 90% of the dose to the thyroid, as shown in Figure 3 for Harry fallout at St. George, Utah. A small thyroid dose contribution is also made by ^{132}Te and ^{133}I , while other radionuclides make only trivial additions.

As a rule, thyroid doses in communities relatively close (within ~ 200 miles) to the NTS were dominated by a few events, even though many events may have contributed to long term dose. Using St. George as an example, events Harry and Smoky happened to produce fallout patterns that gave rise to adult thyroid doses in excess of 1 rad and median infant doses among individuals of up to 83 rad (Table 4). The variations in dose produced by different fallout events depend primarily on the amount of fallout deposited in the main food-producing areas for a particular community, and secondarily on the seasonal timing of the deposition. As Table 4 shows, age also has a large effect on thyroid dose, with dose increasing for the younger members of the population.

The results in Table 4 also illustrate that the basis for selection of parameter uncertainties affects not only the GSD values, but also the median

Figure 2. Percentage of the total fallout deposition radioactivity contributed by various radionuclides for event Harry at St. George, Utah.

Figure 3. Percentage of total thyroid dose contributed by various radionuclides for event Harry at St. George, Utah.

Table 4. Thyroid doses from ingestion for unspecified individuals living in St. George, Utah. Rural lifestyle assumed. The six events selected were those producing the greatest thyroid doses. Results for males and females are averaged.

Event (date)	Uncert. Basis ^a	<u>Infant (0-12 mo)</u>		<u>Child (1-11 yr)</u>		<u>Teen (12-18) yr)</u>		<u>Adult (≥ 19 yr)</u>	
		Dose (rad)	GSD	Dose (rad)	GSD	Dose (rad)	GSD	Dose (rad)	GSD
Harry (5/19/53)	indiv.	83	2.4	40	2.1	17	2.3	5.1	1.9
	mean	67	2.2	32	2.0	14	2.0	4.0	1.8
Smoky (8/31/57)	indiv.	24	2.6	10	2.4	4.3	2.6	1.3	2.1
	mean	20	2.4	8.5	2.2	3.4	2.2	1.0	2.0
Annie (3/17/53)	indiv.	3.5	2.4	2.0	2.2	0.93	2.4	0.27	2.1
	mean	2.7	2.2	1.5	2.1	0.74	2.1	0.21	2.0
Zucchini (5/15/55)	indiv.	3.2	2.6	1.5	2.3	0.63	2.5	0.19	2.1
	mean	2.6	2.4	1.2	2.2	0.50	2.2	0.15	2.0
Simon (4/25/53)	indiv.	2.1	2.5	0.93	2.3	0.39	2.3	0.11	2.0
	mean	1.7	2.2	0.75	2.0	0.31	2.0	0.09	1.9
Tesla (3/1/55)	indiv.	1.8	2.4	1.0	2.2	0.50	2.3	0.14	2.1
	mean	1.4	2.1	0.8	2.0	0.39	2.0	0.11	2.0

^aUncertainty basis reflects either that for individuals (indiv.) within the population or that of the population mean (mean).

doses. In the first set of Monte Carlo computations, parameter uncertainties were chosen to represent those of individuals within the population. These runs produced higher median values and higher GSDs than later runs using uncertainty estimates of the population mean. For application to collective dose estimates, we believe that dose statistics based on uncertainty of the populations means are appropriate. On the other hand if one is asking about individuals in the population, such as dose to the maximally-exposed person, the statistics based on individual uncertainties seem most appropriate.

The larger values of the geometric mean dose for individuals as compared to population estimates are due entirely to the larger values assigned to the geometric standard deviations on the food consumption rates. In a lognormal distribution, the arithmetic mean lies to the right of the geometric mean. The value of the arithmetic mean is determined by the values of the geometric mean and the geometric standard deviation:

$$\mu_x = e^{\left[\ln(GM_x) + \frac{(\ln(GSD_x))^2}{2} \right]}$$

By holding the geometric mean constant and increasing the geometric standard deviation, the arithmetic means of the dose estimates were increased. The larger values of the arithmetic means were then propagated through the computations of the model to yield larger median doses for individuals.

As a benchmark for the thyroid dose computations, it is useful to compare the results in Table 4 to earlier estimates prepared by other investigators. Anspaugh et al., 1990 compared seven thyroid dose estimates for infants living in St. George following event Harry. The best estimates from individual investigators ranged from 68 to 84 rads. These values compare

quite favorably to our median estimates of 67 rads to be applied to the population mean and 83 rads when considering the median of all individuals. The ranges of possible estimates from the earlier investigations varied from 20 to 700 rads, while our 95% confidence limits based on the GSD values in Table 4 would range from 14 to 478 rads.

In the Phase II areas further out from the NTS (Beck and Anspaugh, 1991) doses were computed for individual counties, rather than by individual named communities. However, the computations were broken down by three representative lifestyles, namely urban (> 25,000 residents), town (2,000-25,000 residents), and rural (< 2,000 residents). Various assumptions about food consumption patterns and sources of foods were used for the different lifestyle categories (Whicker et al., 1990). As Table 5 illustrates for thyroid doses in Salt Lake County, differences among lifestyle categories did not tend to be large. Furthermore, the rankings were not consistent from event to event. This suggests that the complex milk and food distribution networks tend to mask lifestyle differences and that the seasonal timing of fallout deposition can influence the doses to persons representing the various lifestyles in different ways.

In the ordered list of individual organ doses (e.g. Table 2), total body doses were roughly in the mid-dose range, as might be expected. In terms of general cancer risk, it is the total body dose that should be most comparable to whole body exposures from external gamma radiation. Dose estimates for events producing the highest total body doses from internal emitters to unspecified individuals in St. George, Utah are shown in mrad in Table 6. The highest dose producing event, Harry, yielded median total body doses of about 50 mrad to teens and adults and roughly 100 mrad to infants and children.

Table 5. Thyroid doses from ingestion to unspecified individuals living in Salt Lake County, Utah. Uncertainty estimates reflect that for individuals within the population. Results for males and females are averaged.

Event (Date)	Lifestyle	Infant (0-12 mo)		Child (1-11 yr)		Teen (12-18 yr)		Adult (≥ 19 yr)	
		Dose (rad)	GSD	Dose (rad)	GSD	Dose (rad)	GSD	Dose (rad)	GSD
Easy (5/7/52)	urban	7.9	2.3	4.2	2.2	1.8	2.3	0.40	2.1
	town	8.2	2.4	4.0	2.4	1.7	2.1	0.40	2.1
	rural	7.6	2.5	3.7	2.3	1.5	2.1	0.38	2.1
Harry (5/19/53)	urban	3.8	2.5	1.7	2.7	0.71	2.7	0.11	2.6
	town	3.1	2.7	1.3	2.8	0.50	2.4	0.09	2.5
	rural	1.2	2.6	0.51	2.6	0.20	2.3	0.04	2.4
Nancy (3/24/53)	urban	3.7	2.1	2.4	2.1	1.1	2.2	0.33	2.1
	town	4.4	2.3	2.6	2.1	1.1	2.0	0.34	2.2
	rural	5.3	2.4	3.0	2.2	1.3	2.0	0.37	2.2

Table 6. Total body doses from ingestion for unspecified individuals living in St. George, Utah. Rural lifestyle assumed. The six events selected were those producing the greatest total body doses from ingestion. Results for males and females are averaged.

Event (date)	Uncert. Basis ^a	<u>Infant (0-12 mo)</u>		<u>Child (1-11 yr)</u>		<u>Teen (12-18 yr)</u>		<u>Adult (≥ 19 yr)</u>	
		Dose (mrad)	GSD	Dose (mrad)	GSD	Dose (mrad)	GSD	Dose (mrad)	GSD
Harry (5/19/53)	indiv.	110	1.7	81	1.6	47	1.7	48	1.7
	mean	80	1.5	59	1.5	33	1.5	33	1.5
Smoky 8/31/57)	indiv.	23	2.1	14	2.6	7.2	2.4	7.1	2.2
	mean	17	2.1	10	2.5	5.2	2.3	5.1	2.1
Annie (3/17/53)	indiv.	6.6	1.7	5.0	1.7	3.3	1.9	3.4	1.9
	mean	4.7	1.5	3.6	1.5	2.3	1.7	2.4	1.6
Zucchini (5/15/55)	indiv.	4.4	1.8	2.9	1.7	1.7	1.8	1.8	1.8
	mean	3.2	1.6	2.1	1.6	1.2	1.6	1.2	1.6
Simon (4/25/53)	indiv.	2.3	1.7	1.3	1.6	0.79	1.7	0.81	1.7
	mean	1.7	1.6	0.96	1.5	0.56	1.5	0.56	1.5
Tesla (3/1/55)	indiv.	3.0	1.7	2.4	1.8	1.6	1.9	1.7	1.9
	mean	2.1	1.5	1.7	1.5	1.1	1.6	1.1	1.6

^aUncertainty basis reflects either that for individuals (indiv.) within the population or that of the population mean (mean).

Although age significantly affects total body doses, this effect is considerably less than that for thyroid doses. The GSD values are considerably lower for total body than thyroid doses because longer-lived radionuclides are involved and uncertain events tend to even out somewhat when temporally-variable processes are integrated, thus effectively time-averaged.

The six events listed in Table 6 account for nearly 97% of the total whole-body dose summed over all events that produced measurable fallout in the St. George region. In Table 7, the 37 events producing over 1 μ rad to the total body of St. George adults are listed by rank. Some 74% of the total dose was produced by the Harry event alone, while 99% of the total was produced by 10 events. The total from all events, about 65 mrad, was only about 2% of the total external exposure estimated for St. George by three separate investigators (Henderson and Smale, 1990). Clearly, with the dramatic exception of the thyroid gland, and possibly the lower large intestine in some cases, the external gamma ray exposures from fallout on the ground dominated the total organ doses from all pathways. The contribution from inhalation was substantially less than that from ingestion (Ng et al., 1990).

The contribution of various radionuclides to the total body dose was examined for St. George. The dominant radionuclide was ^{137}Cs , accounting for about 50% of the total body dose (Figure 4). Of secondary importance were ^{90}Sr (~ 15%), ^{89}Sr (~ 10%) and ^{131}I (~ 10%).

A number of types of food contributed significantly to internal total body doses (Table 8). As expected, the relative contributions were dependent on age and timing of the fallout event. Milk dominated only for infants,

Table 7. Ranked list of test events producing at least one microrad from ingestion to the total body of unspecified adults in St. George, Utah. Rural lifestyle assumed. Results for males and females are averaged.

Event	Median Dose (mrad)	Cumulative % of Total	Event	Median Dose (mrad)	Cumulative % of Total
Harry	48	74%	Apple 2	0.022	
Smoky	7.1		Boltzmann	0.020	
Annie	3.4	90%	Hood	0.018	
Zucchini	1.8		Small Boy	0.018	
Tesla	1.7	95%	Able	0.018	
Simon	0.81		Post	0.015	
Met	0.45		Pin Stripe	0.012	
Easy	0.32		Charleston	0.011	
Priscilla	0.30		Morgan	0.008	
Fox	0.28	99%	Hornet	0.007	
George	0.10		Dog	0.007	
Dixie	0.074		Ray	0.006	
Turk	0.055		Newton	0.006	
Wilson	0.046		Baker	0.005	
Apple 1	0.045		Charlie	0.004	
Grable	0.044		Bee	0.002	
Galileo	0.041		Ruth	0.001	
How	0.030		Climax	0.001	100%
Badger	0.029				

Total, 37 events: 64.8 mrad

Figure 4. Percentage of the total body dose contributed by various radionuclides for event Harry at St. George, Utah.

Table 8. Relative contribution (%) of different food types to total body doses via ingestion to unspecified males at St. George, Utah.

Food Type	Event Harry (5/19/53)				Event Annie (3/17/53)			
	Age Group (years)				Age Group (years)			
	< 1	1-11	12-18	≥ 19	< 1	1-11	12-18	≥ 19
Milk	50	27	27	17	38	20	18	11
Milk Products	18	9	3	4	16	7	3	3
Cottage Cheese	--	--	5	13	--	--	4	10
Hard Cheese	--	--	< 1	< 1	--	--	--	--
Eggs	4	4	6	4	8	7	10	7
Leafy Vegetables	2	13	10	10	2	9	6	6
Other Vegetables	8	6	5	4	14	10	6	5
Grains	9	22	14	13	3	7	4	3
Meats	7	17	28	33	16	35	47	54
Soil	2	2	1	< 1	4	5	2	1

while meats were a dominant source of dose for adults and teenagers. Eggs, vegetables, and grains all made significant contributions in some situations.

The values of all 4,933 calculated adult thyroid doses, representing all Phase I and II locations and all events, are plotted in Figure 1 against the H+12 hour survey meter reading. Note the use of log-log coordinates to accommodate the 5-6 order of magnitude ranges in values. As explained in the section on verification and face validity (p. 19), the large variations in thyroid dose for a given survey meter reading reflects the complex of variables that modify the organ doses (e.g. time of year, agricultural practices, etc.). Clearly, however, the amount of fallout deposited (estimated from the H+12 hour survey meter reading), explains most of the overall variability in the universe of estimated thyroid doses. It may be noted from Figure 1 for adult thyroid doses, that only in a small fraction of instances were the estimated median values over 1 rad. Dose estimates of over 10 rad were extremely unlikely in the Phase I and II adult population.

Similar plots for thyroid doses are given for teenagers, children, and infants in Figures 5 through 7, respectively. As noted earlier (Tables 2, 4, and 5), thyroid doses increase for the younger age groups. In the cases of infants and children, there were a very small fraction of the cases where thyroid doses probably exceeded 100 rads. Even for infants, however, the vast majority living within the Phase I and II study area likely received less than a few rads from NTS fallout.

One interesting question is the strength of correlations between the internal doses to various organs. One would generally expect strong correlations because of the parameters in common that affect all organs. However, since the availability of different radionuclides to the various

Figure 5. Thyroid doses of teenagers (12-18 years) as a function of H + 12 hour survey meter reading. All test events and Phase I and II locations are included. Doses are in rad.

Figure 6. Thyroid doses to children (1-11 years) as a function of H + 12 hour survey meter reading. All test events and Phase I and II locations are included. Doses are in rad.

Figure 7. Thyroid doses to infants (0-12 Months) as a function of H + 12 hour survey meter reading. All test events and Phase I and II locations are included. Doses are in rad.

organs is dependent on the composition of the fallout and agricultural and food source patterns related to season of the year, perfect correlations would not be expected. One example is a plot of adult thyroid dose versus adult whole body dose for all events and locations (rural lifestyle) within the Phase I and II regions (Figure 8). The fitted power function for these data was $Y = 89 X^{0.99}$, where Y is thyroid dose in rad and X is whole body dose in rad. The Chi-square was 1.974 and the linear correlation coefficient was 0.97, thus the probability of a significant correlation is essentially 1.0.

A similar plot for the lower large intestine dose (rads) versus whole body dose (rads) for rural lifestyle adults within the Phase I and II regions (all events) is shown in Figure 9. In this case $Y = 22 X^{1.09}$ with a Chi-square of 6.3 and a linear correlation coefficient of 0.98. Again, the probability of a significant correlation was essentially 1.0. Visual inspection of Figures 8 and 9 suggests a generally tighter correspondence between the lower large intestine and whole body doses than that between the thyroid and whole body. We believe this is logical because of the strong effect of ^{131}I in the thyroid dose and the extreme seasonal dependency of ^{131}I transport from fallout to the human thyroid.

Collective Dose Estimates

Collective dose estimates (in person-rads) were computed for each organ, taking into account dose to the mean unspecified individual and the number of individuals by location, time period, age and sex (Kirchner and Whicker, 1992). A general summary representing all test events and localities within the Phase I and II region is shown by age group for selected organs in Table 9. The Phase I and II region includes the entire states of Nevada, Utah, Arizona, and

Figure 8. Relationship between thyroid and total body dose. All test events and Phase I and II locations are included. Rural lifestyle was assumed. Doses are in rad.

Figure 9. Relationship between dose to the lower large intestine and to the whole body. All test events and Phase I and II locations are included. Rural lifestyle was assumed. Doses are in rad.

Table 9. Collective ingestion dose estimates (person-rads)^a for all events and all Phase I and II locations.^b Rural lifestyle assumed for counties.

Age Group	Thyroid	Lower Large Intestine	Bone Surface	Total Body
Infant (0-12 mo)	1.8×10^6	4.7×10^4	1.5×10^4	1.9×10^3
Child (1-11 yr)	8.4×10^6	2.5×10^5	3.2×10^4	1.2×10^4
Teen (12-18 yr)	1.6×10^6	5.5×10^4	1.8×10^4	4.0×10^3
Adult (≥ 19 yr)	1.8×10^6	2.2×10^5	4.3×10^4	1.7×10^4
All Ages	1.4×10^7	5.7×10^5	1.1×10^5	3.5×10^4

^a Uncertainties in estimates, expressed as GSD values, ranged from 1.04 to 1.11.

^b See Church et al., 1990 for geographic definition of Phase I and Phase II.

New Mexico, and portions of five adjoining states (Church et al., 1990). The simple arithmetic sums across age groups represents collective internal dose estimates from ingestion for the entire Phase I and II population. As expected, the collective thyroid dose of 1.4×10^7 person-rad, ranged from over 1 to about 3 orders of magnitude greater than collective doses to other organs. It is a factor of 400 higher than that of the total body, for example.

Uncertainties in the collective dose estimates were much lower than was the case for dose estimates for unspecified individuals. For example, the GSD values for the collective organ doses for the Phase I and II regions ranged from only 1.04 to 1.11. This appears to result from the summations across events and locations, as well as the use of uncertainties in dose that represent the population mean as opposed to individuals within the population. The formulations used to propagate the uncertainties for collective dose are found in Kirchner and Whicker (1992).

Although it was not within our charge to evaluate risk, we were curious about potential health effects, in terms of the theoretical numbers of fatal cancers that might be incurred by the people of the Phase I and II populations, and those in selected communities. These computations were facilitated by the use of organ-specific risk factors for lifetime fatal cancers in a population of all age groups after low dose, low dose rate exposure (International Commission on Radiological Protection, 1991). The application of these all-age-group population risk factors obviates the need to use age-dependent risk factors and to deal with the problem of individuals receiving multiple exposures over a period of perhaps a decade, during which time their risk per unit dose may change. We suspect this simple approach

creates some bias, but doubt that it would be large over the entire population. The estimates of the numbers of lifetime fatal cancers were taken as the product of the collective dose (in person rad) and the ICRP risk factor (rem^{-1}), with the assumption of a quality factor of unity (i.e. $1 \text{ rad} = 1 \text{ rem}$). The latter assumption seems reasonable since the doses were received primarily by gamma and beta radiations.

The fatal cancer estimates thus computed are presented for those organs receiving the highest doses; namely, thyroid, lower large intestine, bone surface, and total body (Table 10). Table 10 lists estimated numbers of cancers for the entire Phase I and II region, for eight counties that experienced the highest collective doses, for Las Vegas, Nevada, and for comparison, St. George, Utah. As expected, the thyroid and lower large intestine would be the most likely sites for cancer, based strictly on the dose from internal emitters taken in by ingestion. The actual expected numbers of cancers resulting from exposure of the whole body to fallout on the ground would inflate the numbers for bone cancer and for other cancers considerably. Table 10 reflects clearly that the number of predicted cancers in a population is affected both by the numbers of exposed people, as well as by the median dose. The relatively large populations in Salt Lake City, Las Vegas, Albuquerque (Bernalillo County), and Los Angeles provide the primary explanation for the rankings of these areas in Table 10. Salt Lake County residents, however, though fewer in number than Los Angeles, for example, received much higher doses on average. Residents of St. George, Utah, though receiving much higher doses than people in the other areas listed in Table 10, were too few in number to rank high in the total number of predicted fatal cancer cases. In fact, less than one single case of fatal thyroid cancer

Table 10. Estimated numbers of lifetime fatal cancers in all age groups resulting from ingestion of NTS fallout. All NTS events are included. Risk factors are based on the 1990 recommendations of the ICRP.^a

Population (1955 Census)	Number of Cancers			
	Thyroid	Lower Large Intestine	Bone Surface	Total Body
Phase I and II Region ^b (2.0×10^7)	112	49	1	18
Salt Lake Co., UT (3.3×10^5)	16	9	0.09	3
Utah Co., UT (9.4×10^4)	9	3	0.04	1
Weber Co., UT (9.7×10^4)	5	3	0.03	0.9
Las Vegas, NV (8.8×10^4)	5	0.8	0.01	0.4
Bernalillo Co., NM (2.0×10^5)	3	3	0.03	0.9
Los Angeles Co., CA (5.1×10^6)	3	2	0.02	0.8
San Bernardino Co., CA (3.9×10^5)	3	1	0.01	0.4
Ada Co., ID (2.4×10^5)	3	0.7	0.01	0.5
Maricopa Co., AZ (5.0×10^5)	2	2	0.02	0.6
St. George, UT (4.8×10^3)	0.9	0.4	< 0.01	0.1

^a International Commission on Radiological Protection (1991) risk factors for fatal cancer in a population of all ages after low dose, low dose rate exposure (rem^{-1}): Thyroid = 8×10^{-6} ; Colon = 8.5×10^{-5} ; Bone Surface = 5×10^{-6} ; and Total Body = 5×10^{-4} . Since the internal exposures were dominated by beta/gamma emitters, the quality factor was taken as 1.0; thus 1 rad = 1 rem.

^b See Church et al., for geographic definition of Phase I and Phase II regions.

would be predicted for St. George. Approximately three lifetime cases of spontaneous, fatal thyroid cancer would be expected in a population the size of St. George (UNSCEAR 1988) based on a mortality-incidence of about 6×10^{-4} .

The specific counties listed in Table 10 only account for about 40-50% of the total fatal cancers for the Phase I and II region. This indicates that the incidence of such health effects would be expected to occur over a very wide geographic area. The communities in the Phase I, "near-in" area that received the highest doses were small, thus fewer people were at risk. We believe this analysis supports the concept that although ingested NTS fallout potentially caused from perhaps a dozen to a few hundred fatal cancers in the Phase I and II region, this incidence is probably not sufficient to statistically alter the overall fatal cancer rate for the region. Assuming a spontaneous fatal cancer incidence of roughly 20%, the Phase I and II region population should experience approximately 4×10^6 cancer deaths. Of course, it is well-known that the actual cause of any single potentially-radiogenic cancer in a population can never be proven; it can only be inferred statistically (NCRP 1992).

Table 10 presented estimates of the expected numbers of lifetime fatal cancers in specific, geographically-defined populations. It is also of interest to look at typical risks to individuals. Table 11 presents individual risks for St. George residents and Phase I and II residents by assuming the median dose per individual to be the collective dose divided by the population, estimated from the 1955 census. This procedure of course, fails to account for wide geographic differences within the Phase I and II region, age/sex differences, and individual residence histories. Therefore, these individual risk estimates are of limited utility. They do illustrate

Table 11. Estimated individual lifetime risk of a fatal cancer in all age groups resulting from ingestion of NTS fallout. All NTS events are included.

Organ	Population (1955 Census)	Collective Dose (person-rads)	Median Dose Per Individual (rad)	Risk Factor ^a (rad ⁻¹)	Median Individual Risk
Thyroid	Phase I&II (2.0 x 10 ⁷)	1.4 x 10 ⁷	0.70	8 x 10 ⁻⁶	5.6 x 10 ⁻⁶
	St. George, UT (4.8 x 10 ³)	1.07 x 10 ⁵	22	8 x 10 ⁻⁶	1.8 x 10 ⁻⁴
Lower Large Intestine	Phase I&II	5.7 x 10 ⁵	2.9 x 10 ⁻²	8.5 x 10 ⁻⁵	2.4 x 10 ⁻⁶
	St. George	4.5 x 10 ³	0.94	8.5 x 10 ⁻⁵	8.0 x 10 ⁻⁵
Bone Surface	Phase I&II	1.1 x 10 ⁵	5.5 x 10 ⁻³	5 x 10 ⁻⁶	2.8 x 10 ⁻⁸
	St. George	7.9 x 10 ²	0.17	5 x 10 ⁻⁶	8.5 x 10 ⁻⁷
Total Body	Phase I&II	3.5 x 10 ⁴	1.8 x 10 ⁻³	5 x 10 ⁻⁴	9.0 x 10 ⁻⁷
	St. George	2.8 x 10 ²	5.8 x 10 ⁻²	5 x 10 ⁻⁴	2.9 x 10 ⁻⁵

however, that individual and population-level risks are quite different. Whereas the population risk for the Phase I and II region exceeds that for St. George for example (Table 10), the individual risks for St. George residents are much higher than those for people chosen randomly from the Phase I and II region (Table 11). The chance of the average individual living in St. George getting a fatal thyroid cancer due to ingestion of NTS fallout was about two chances in 10,000. On the other hand, certain individuals by virtue of age, food habits, etc. might have had a higher risk.

ANCILLARY ACCOMPLISHMENTS AND CONTRIBUTIONS

There were a number of accomplishments, contributions, and recognitions resulting from the support of CSU to conduct the pathway analysis task that were not originally expected as direct products of the work. We feel that the encouragement, financial support and freedom permitted by DOE/NV00 management created the possibility to perform our expected tasks to the fullest and most creative extent possible. We also believe this situation created the opportunity to explore some new areas and to share the expertise gained with other investigators and projects within the United States and also abroad. There is substantial evidence that not only did ORERP in general, and the pathway analysis task, in particular, contribute substantially to the art and science of dose reconstruction, but that our efforts have been widely and positively recognized. Finally, several young investigators received support to further their graduate education through ORERP, contributing substantially to the program in the process. These individuals will be some of the leaders in the field in the years ahead. In this section, these ancillary accomplishments and contributions are summarized and documented.

International Activities

BIOMOVs

BIOMOVs is an acronym for Biospheric Model Validation Study, an international cooperative effort to test models that predict the transport of radionuclides and other trace substances through agricultural ecosystems to food products and ultimately, humans. BIOMOVs was initiated by the Swedish National Institute of Radiation Protection, but later also supported by organizations from at least 13 other countries. The original formal agreement to launch BIOMOVs occurred at a 1986 meeting in Paris that was attended by representatives of most participating countries. After the Paris meeting, some 11 international workshops were held in at least eight countries over a four year period. The final meeting was concluded as an international symposium held October 8-19, 1990 in Stockholm.

Ward Whicker attended a meeting between the BIOMOVs organizers and the Office of Health and Environmental Research at DOE Headquarters in April 1986. DOE expressed little interest in the effort, thus we initially did not see how we could become involved. However, a year later, it was apparent that the Chernobyl accident would provide unique opportunities to test food chain transport models with real time series data in a variety of agricultural ecosystems throughout the northern hemisphere. Prior to Chernobyl, BIOMOVs was primarily designed as a model intercomparison exercise, largely using hypothetical scenarios. Because of the new opportunity to critically test PATHWAY predictions, DOE/NV00 agreed to support our involvement in BIOMOVs.

Our first formal participation was at a meeting at the Grand Canyon in December 1987. It was clear at this meeting that we could contribute significantly to BIOMOVs because PATHWAY was one of only about three or four

models among some 25 that were truly mechanistic, dynamic and fully testable against time series data. Furthermore, we had already been involved in model testing through validation exercises and uncertainty/sensitivity analysis. In these areas we had as much or more experience than the other participants. Over the following 2 1/2 years we participated very actively in meetings held in Budapest (Hungary), Tokai (Japan), Fort Collins, El Poular (Spain), Ottawa (Canada) and Stockholm (Sweden).

We believe we helped to set a tone for critical, open evaluation of the models. An initial protective attitude about models was gradually replaced with a general attitude of being very open and constructive about weaknesses in the models. We were openly critical about the weaknesses in PATHWAY from the beginning, and this seemed to help initiate a change in attitude. The meetings became very constructive in the sense of analyzing the problems of models and looking for solutions and improvements.

Some of our most tangible products from the BIOMOVs involvement were the tests of PATHWAY model predictions against those of other models and real data sets resulting from the Chernobyl contamination (Nielsen, et al. 1991). This exercise was very time consuming but revealed that, in general, PATHWAY performed quite well. Where it did not, the reasons for mispredictions were evident (see pg. 22). We were not particularly troubled by the cases of poor prediction because PATHWAY was parameterized for agricultural conditions in the southwestern U.S. during the 1950's. Had we specifically parameterized the model for the actual conditions corresponding to post-Chernobyl data sets, the model predictions would have been extremely gratifying.

Another product of the effort was a technical report (Whicker, 1990) and a proceedings paper (Whicker et al., 1991) that dealt with the relative

importance of ingestion in multiple pathway dose assessments. This issue was examined by BIOMOVs because the models dealt primarily with ingestion. Under what situations and scenarios would ingestion be a dominant dose-producing pathway, and when could ingestion be ignored? A matrix of release scenarios and radionuclides was prepared and within each radionuclide/release scenario cell, the relative importance of ingestion, inhalation, and external exposure was examined. The general conclusions from this particular effort are listed in APPENDIX E.

Some of the latest and most in-depth thinking on the subject of developing model credibility was articulated in a paper by Kirchner (1991). This effort, inspired partly by the BIOMOVs study, is important to ORERP and other dose reconstruction efforts because credibility of the results and models that produce them is often the primary measure of the success of the dose reconstruction effort. As a developing art and science, dose reconstruction projects can benefit greatly from the ideas in this paper.

A guide on objective model testing was prepared by Breshears and Kirchner (1988) for use by BIOMOVs participants. It is apparent that many modelers are not willing or able to devote the time and effort necessary for critical, objective model testing, but for those who do, this guide, though unpublished, is valuable. We believe we influenced a number of BIOMOVs participants to adopt objective statistical techniques with which to judge the performance of models against real world data.

Tom Kirchner has maintained involvement in BIOMOVs II, which is a refined continuation of the original program. He is the leader of the Uncertainty/Validation working group. In this capacity, he has a strong

influence on international developments in this area. The ORERP experience provides a base of expertise for this effort.

IAEA Document on the Need for Radiation Protection Standards
for Plants and Animals

In 1986, F.W. Whicker was asked by the International Atomic Energy Agency to help develop a report dealing with the question of whether specific radiation protection standards are needed for species other than humans. It has long been implicitly assumed that if radioactive emissions to the environment are controlled to the extent that dose standards for humans are not exceeded, then populations of plants and animals exposed to the same emissions will not be threatened or measurably impacted. Although this question had received cursory examination before, this was the first substantial effort at the international level to probe this general assumption.

The basic approach was first to conduct a comprehensive literature review on the minimum doses and dose rates required to affect the ability of populations to sustain their numbers and general vigor. As part of this process, it was necessary to define those endpoints most crucial to the long term viability of populations. In general, reproduction appeared to be the limiting endpoint under conditions of either acute or chronic radiation exposure. Thus, the first objective became one of estimating a minimum dose rate required to produce observable deleterious effects on reproduction of aquatic and terrestrial organisms.

The second step was to estimate the maximum potential dose rates to the reproductive organs/tissues of plants and animals at radionuclide release or

deposition rates that would produce the maximum permissible dose rate (1 mSv/year) to members of the public. Finally, these dose rates were compared to those required to produce effects on reproduction of aquatic or terrestrial organisms.

The calculations were carried out for three different radionuclide release scenarios: (1) controlled release to the atmosphere, (2) controlled releases to a freshwater aquatic ecosystem, and (3) uncontrolled use of a shallow land nuclear waste repository by humans and other organisms. The calculations were made for radionuclides that represent a diverse array of physical, chemical and biological properties. The radionuclides considered in at least one of the three scenarios include ^3H , ^{14}C , ^{32}P , ^{60}Co , ^{90}Sr , ^{95}Zr , ^{99}Tc , ^{129}I , ^{131}I , ^{137}Cs , ^{226}Ra , ^{235}U , ^{238}U , ^{239}Pu and ^{241}Am .

The PATHWAY model was used in the controlled atmospheric release scenario (IAEA, 1992). First, it was used to estimate the radionuclide deposition rates ($\text{Bq}/\text{m}^2\text{-day}$) that would produce an effective dose equivalent rate of 1 mSv/year to humans from all pathways. Second, the model was used to estimate the equilibrium concentrations in plant and animal tissues from the deposition rate that would produce 1 mSv/year to humans. Doses to plant and animal tissues were estimated from first principles and conservative, simplifying assumptions about geometry, energy absorption, etc. The calculations were reviewed by numerous experts in the international community.

There was broad, general consensus that chronic radiation exposures below 1 mGy (0.1 rad) per day would cause no measurable harm to plant or animal populations, both aquatic and terrestrial. The calculations and expert reviews also concluded that in practice, if human radiation exposures are limited to less than 1 mSv/year, chronic dose rates to plants and animals

should be well below 1 mGy/day. Therefore, specific radiation protection standards for organisms other than man should not be needed. Potential caveats to these general conclusions however, might include special ecological situations not considered, rare or endangered species with long life spans, and combined stresses from factors other than radiation exposure.

We believe this report (IAEA, 1992) will be cited heavily in the future by many countries, for a wide variety of scientific and regulatory purposes. The primary authors of the report (see preface), were F. W. Whicker, B. G. Blaylock and D. S. Woodhead.

Contributions to Other Dose Assessments

During the course of the ORERP study, and particularly during the last five years of it, several other environmental dose reconstruction projects were initiated. These were related to fallout from NTS events, historical releases from other DOE nuclear weapons complex facilities, and the Chernobyl accident. The methodologies developed within ORERP received rather wide notice in the scientific community that deals with environmental radioactivity; thus it was useful for other studies to benefit from our experience. Among the other dose assessments that requested specific assistance and advice from the Pathway Analysis Task Group were:

- NCI study on thyroid cancer and leukemia incidence, and supporting dosimetry, University of Utah, Salt Lake City.
- NCI study on thyroid dose to the American public from NTS fallout, the U.S. Department of Energy's Environmental Measurements Laboratory, New York City.

- Internal dose estimates from Chernobyl, M. Goldman, University of California, Davis.
- Intake per unit deposition values for estimating internal doses from Chernobyl, UNSCEAR, Vienna, B. G. Bennett.
- INEL study on public radiation doses from releases at the Idaho National Engineering Laboratory, U. S. Department of Energy.
- PNL study on historical doses to the public from releases at Hanford, Washington, Battelle-Pacific Northwest Laboratories.

While individually, these other studies did not require a great effort on our part, in total they consumed a rather significant amount of time, particularly from F. W. Whicker and T. B. Kirchner. Our ability to assist these other investigations is one indication of the value of ORERP to the art and science of dose reconstruction.

Fallout ^{137}Cs in Sediments of Utah Lakes

In 1983, we initiated a small program to examine the vertical distribution of ^{137}Cs in sediment cores from lakes in Utah. Undisturbed sediments can provide a temporal record of fallout deposition because ^{137}Cs usually attaches very strongly to clay and silt particles and remains in place. Of particular interest to ORERP was the question of whether ^{137}Cs profiles in sediment cores could provide additional information about the timing and magnitude of NTS fallout in specific geographic locales.

In total, we examined 15 impoundments in Utah, two in Oregon, and one in Colorado. There was evidence for enhanced fallout ^{137}Cs deposition during the period of most intense testing activity at the NTS (1951-57) in two impoundments in southwestern Utah. However, our technique for estimating NTS

fallout relative to global fallout yielded greater within-lake variability than between-lake variability. Thus, in general, differences between impoundments in relative deposition of NTS fallout could not be statistically demonstrated.

Our data did prove useful for estimating sedimentation rates, as well as cumulative ^{137}Cs deposition. Estimated cumulative deposition and mean sedimentation rates were correlated, and both were inversely related to impoundment elevation.

This work has resulted in three publications. The original work and data are embodied in a Master of Science Report by Susan (Tench) Jacobi. A further analysis of the data is found in a report to DOE by Whicker, Whicker and Jacobi (1992). Finally, the latter report, with only slight modification, was accepted by the Journal of Environmental Radioactivity in March 1993 for publication (Whicker, Whicker and Jacobi, In Press).

Variability in the Radionuclide Content of Human Tissues

An important goal of the PATHWAY ANALYSIS TASK was the proper estimation of uncertainty in radionuclide ingestion and the resulting dose. Part of this process involved the attempt to understand sources of uncertainty. The two major sources of uncertainty in model predictions are lack of knowledge about parameters and processes and the natural, inherent variability of the system being simulated. There is no way to reduce natural variability, but one can attempt to understand better the magnitude of this source by reviewing actual data sets representing radionuclide concentration distributions within defined populations.

During 1989, Dr. S. A. Ibrahim spent a modest amount of time reviewing literature on observed burdens of ^{239}Pu , Th isotopes, and ^{131}I in human tissues. This effort was documented in our progress reports dated 1/11/89, 4/19/89, and 8/30/89. The 4/19/89 report (Appendix 4) contained distributional data for ^{239}Pu and Th. The ^{131}I review was well underway as of 8/30/89. It was our intent to publish this information; however little progress was made after 1989 due to insufficient funding and the need for Dr. Ibrahim to pursue other work.

Professional Awards

In 1990, F. W. Whicker received the U.S. Department of Energy's E. O. Lawrence Award. Included in the citation for the award was the development of the PATHWAY model, which has received national and international recognition as one of the world's state-of-the-art predictive tools for radionuclide transport. In 1991, Whicker also received the Glover Gallery Award for Distinguished Faculty at Colorado State University. This award also recognized the PATHWAY model as one of his important achievements.

Education

During the past 10 years or more, a serious shortage of qualified health physicists and radiological health sciences personnel has developed in the United States. The U.S. Department of Energy has recognized this shortage, as well as the importance of education in general. We are proud of the fact that DOE support of the Pathway Analysis Task enabled us to support a number of graduate students at CSU. These students all made very important, cost-

effective contributions to the project. Some five students completed M.S. degrees in connection with the project (D. D. Breshears, T. A. Ikenberry, S. T. Jacobi, P. C. Desjardins, and D. L. Clark). One Ph.D., M. D. Otis, completed a dissertation bearing directly on the project and W. J. Smith III, spent a year in a post-doctoral position working on formulations to describe resuspension.

Approximately 50 other students benefitted in the classroom from the concepts and methodologies developed by the project. F. W. Whicker and T. B. Kirchner have taught radionuclide transport methodologies at several national professional meetings and training courses, including two courses on pathway analysis and uncertainty/sensitivity analysis for the Radiological Assessments Corporation (March 1991, 1992). F. W. Whicker taught an international training course on pathway transport modelling in Mol, Belgium in July 1990, and a pathway modelling course for the Health Physics Society in June 1989.

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APPENDIX A

**FORM: SURVEY OF LIFE-STYLES,
FOOD HABITS, AND AGRICULTURAL PRACTICES
(OMB No. 1901-0235)**

U.S. Department of Energy
Nevada Operations Office
Las Vegas, Nevada 89114

SURVEY OF LIFE-STYLES, FOOD HABITS, AND
AGRICULTURAL PRACTICES

RESPONDENT IDENTIFICATION FORM

In accordance with the Privacy Act, I must inform you that this survey is voluntary; it is being conducted under authority of the Atomic Energy Act of 1954; and all information obtained will be separated irretrievably from the identities of the respondents.

This survey is being conducted by Dixie College on behalf of Colorado State University under contract with the Department of Energy. We are interested in obtaining information on the life-styles, food habits, and agricultural practices of persons living in Washington County, Utah; Iron County, Utah; and Lincoln County, Nevada; between 1951 and 1962 inclusive.

A. Did you live in any of these counties between 1951 and 1962?

Yes ____ No ____

B. Did anyone in your household live in any of these counties between 1951 and 1962?

Yes ____ No ____

(If answers to both questions A and B are no, end interview.)

C. What are the names of those individuals?	D. What is the age of the individual?	E. Is the individual available for interview at this time?		Log Number
		Yes	No	
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____

NOTE TO INTERVIEWER: If respondent is reluctant to give age, find out if respondents are over 40 years and record this information as age. If no respondent is over 40, terminate interview.

SURVEY OF LIFE-STYLES, FOOD HABITS, AND
AGRICULTURAL PRACTICES

NOTE TO INTERVIEWER: Before proceeding with interview:

1. Record sex of respondent. Male _____ Female _____
2. Transcribe age of respondent. _____
3. Record consecutive log number on identification form and on first page of survey.
4. Record location information (mark one):
 - a. Named Community _____
Name of Community _____
Segment in Community _____
 - b. Open Range _____
Name of County _____
Name of Nearest Community _____
 - c. Indian Reservation _____
Name _____

I have some questions to ask about your living patterns in Washington or Iron Counties in Utah or Lincoln County, Nevada, during the time period 1951 to 1962 inclusive. Please confine your answers to a single location within these counties which you consider to be your principal residence.

1. What was the name of the town nearest your principal residence in this area between 1951 and 1962? _____
2. How many years did you live there? _____
3. What was the primary construction of your home? (check one)
 - a. Wood frame including brick veneer _____
 - b. Masonry, stone, or adobe _____
 - c. Other (specify) _____
4. a. Did your home contain a basement? Yes _____ No _____
(If yes, ask b.; if no, skip to 5.)
 - b. Was it used for sleeping? Yes _____ No _____

5. Did your home contain sleeping areas above the main (ground) level?

Yes _____ No _____

I have some questions about your principal occupation. Principal occupation is the one at which you spent the greatest amount of time between 1951 and 1962 while living at the residence mentioned above.

6. What was your principal occupation? _____

7. Please estimate the number of hours you spent out-of-doors on each working day. _____.

8. Please estimate the number of hours you spent out-of-doors on each nonworking day. _____.

I now have questions concerning your general food habits during 1951-1962.

9. What was your primary source of drinking water? (check one)

a. A well _____

b. A treated urban system _____

c. Other (specify) _____

10. a. Did you obtain milk from your own cow? Yes _____ No _____

(If yes, ask b; if no, skip to 11.)

b. When was your cow usually on pasture? From (date) _____ To (date) _____.

11. a. Did you grow leafy vegetables? Yes _____ No _____

(If yes, ask b; if no, skip to 12.)

b. When did you usually harvest your leafy vegetables: From (date) _____ To (date) _____

12. a. Were there infants in your household between 1951 and 1962?

Yes _____ No _____ (If yes, ask b; if no, skip to 13.)

b. Was the principal source of milk for these infants:

(1) Breast feeding? _____

(2) Fresh cow milk? _____

(3) Formula or canned milk? _____

(4) Other? (Specify) _____

I now have some questions about specific food items you may have consumed between 1951 and 1962.

all questions a.-d, have been asked. For daily consumption, consider only days when food item was actually consumed and specify units as given by respondent.

13.		a. About how often did you usually eat (drink) _____; at every meal, several meals/wk., occasionally, or never?				b. About how much _____ did you consume?		c. Was the _____ produced within the county?		d. (Ask only if milk was obtained from a store). What brand of milk did you usually buy?	
		Every Meal	Sevl M/wk	Occas.	Never	(Quant.)	(Units)/(Time)	Yes	No	Don't Know	(Specify)
(1)	Milk	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	_____
(2)	Cheese	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(3)	Ice Cream	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(4)	Eggs	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(5)	Bread/ Pastry	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(6)	Leafy Vegetables	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(7)	Other Vegetables	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(8)	Fruit	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(9)	Beef	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(10)	Lamb/ Mutton	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(11)	Pork	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(12)	Poultry	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(13)	Fish	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(14)	Venison	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(15)	Wild Rabbit	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(16)	Other	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA
(17)	_____	_____	_____	_____	_____	_____	_____/_____	_____	_____	_____	NA

e. Are there other food items you think should be listed? Yes _____ No _____
(List other food items in spaces (16) and (17) of question 13 and repeat a.-c. for these items.)

14. Did you:

- a. Live in town? Yes _____ No _____
- b. Live on a farm or ranch? Yes _____ No _____
- c. Operate a farm or ranch?
(If yes, ask 15; if no, end interview) Yes _____ No _____

15. Did your farm or ranch include:

- a. A dairy? Yes _____ No _____
- b. Livestock production? Yes _____ No _____
- c. Produce production? Yes _____ No _____

16. Did you grow alfalfa on your farm or ranch?

Yes _____ No _____

(If yes, ask 17; if no, skip to 18.)

17. a. What were the usual cutting dates for alfalfa? b. What percent was used locally? c. What percent was shipped elsewhere? d. Where was it shipped?

<u>(Cutting)</u>	<u>(Date)</u>	<u>(%)</u>	<u>(%)</u>	<u>(Destination)</u>
First	_____	_____	_____	_____
Second	_____	_____	_____	_____
Third	_____	_____	_____	_____
Fourth	_____	_____	_____	_____
Fifth	_____	_____	_____	_____

18. Did you grow commercial crops other than alfalfa on your farm or ranch? .

Yes _____ No _____

(If yes, ask 19; if no, skip to 21.)

I have some questions concerning the practices used in growing these crops and the final destination of the products.

19.	(Insert the item in the blank)	a. Did you grow _____?		b. What was your usual plowing date?	c. What was your usual planting date?	d. What was your usual harvesting date?	e. What was your usual plowing depth in inches?	f. What percent of _____ was used locally for:		g. What percent was shipped elsewhere for:		h. Where was it shipped?
		Yes	No	(Date)	(Date)	(Date)	(Depth)	Humans (%)	Animals (%)	Humans (%)	Animals (%)	(Destination)
(1)	Grains	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____
(2)	Sugar Beets	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____
(3)	Potatoes	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____
(4)	Corn	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____
(5)	Green Peas	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____
(6)	Tomatoes	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____
(7)	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____
(8)	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____

20. Did you produce crops other than those identified above? Yes _____ No _____
 (List other crops in spaces (7) and (8) of question 19 and repeat question 19 for these items.)

21. Did you raise farm animals on your farm or ranch? Yes _____ No _____
 (If yes, ask 22; if no, end interview.)

I would like to ask you about the farm animals you raised.

22. a. Did you normally raise ____? b. When were the _____ usually on irrigated pasture? c. When were the _____ usually on native range? d. When were the _____ usually on dry feed? e. Where was the feed obtained?

Insert the farm animal in the blank)

		<u>Yes</u>	<u>No</u>	<u>From</u>	<u>To</u>	<u>From</u>	<u>To</u>	<u>From</u>	<u>To</u>	<u>(Source)</u>
(1)	Dairy Cows	_____	_____	_____	_____	_____	_____	_____	_____	_____
(2)	Beef Cattle	_____	_____	_____	_____	_____	_____	_____	_____	_____
(3)	Sheep	_____	_____	_____	_____	_____	_____	_____	_____	_____
(4)	Goats	_____	_____	_____	_____	_____	_____	_____	_____	_____
(5)	Pigs	_____	_____	_____	_____	_____	_____	_____	_____	_____
(6)	Poultry	_____	_____	_____	_____	_____	_____	_____	_____	_____
(7)	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____
(8)	_____	_____	_____	_____	_____	_____	_____	_____	_____	_____

23. Did you raise farm animals other than those mentioned? Yes ____ No ____
(If yes, write names in (7) and (8) and repeat question 22.)

NOTE TO INTERVIEWER: For question 24, ask only about the farm animals marked yes in question 22a.

The following questions refer to food products obtained from those animals.

24.	a. What were the usual slaughter dates for _____?	b. What percent of the _____ was consumed by family or friends?	c. What percent of the _____ was marketed within the county?	d. What percent of the _____ was shipped elsewhere?	e. Where was the _____ shipped?
	(Date)	(%)	(%)	(%)	(Destination)
(1) Milk	NA				
(2) Beef					
(3) Lamb/Mutton					
(4) Goat Meat					
(5) Pork					
(6) Poultry					
(7) Eggs	NA				
(8) _____					
(9) _____					

25. Did you have any other farm animal products used for human consumption? Yes _____ No _____
 (If yes, write in (8) and (9) and repeat question 24 for these products.)

APPENDIX B

INSTRUCTION BOOKLET FOR SURVEY OF LIFESTYLES, FOOD HABITS, AND AGRICULTURAL PRACTICES (OMB No. 1901-0235)

Modified 9/29/82

INSTRUCTION BOOKLET

FOR

SURVEY OF LIFE-STYLES, FOOD HABITS, AND
AGRICULTURAL PRACTICES

OMB No. 1901-0235

GENERAL APPROACH

1. Identify yourself and affiliation.
2. Clearly state the purpose of the visit
3. Make sure that interviewee understands that the survey is voluntary.
4. Make sure that interviewee is aware that the information provided will be used to estimate or construct radiation dose to an average or typical person in the community. This information will not be associated with or used for any specific individual.
5. Do not ask if the individual is involved in litigation. If a person indicates involvement in a claim, simply point out the voluntary nature of the survey, as well as the fact that the information provided will be irretrievably separated from the individual identity of the respondents. The lawyers representing both sides of the case have agreed that this survey should not be biased on the basis of involvement or potential involvement with litigation.
6. It is critically important that you treat each respondent in a polite, friendly and tactful manner. Some respondents may offer much in the way of superfluous information. Try to listen to a limited amount of this, but don't get involved in lengthy discussions. Answer questions in an honest, straightforward way. Do not try to answer questions such as "How much radiation did we get?" or "Did radiation from fallout cause cancer?"

RESPONDENT IDENTIFICATION FORM

Purpose - (1) To keep track of the progress of the survey.

(2) To determine eligibility of persons for the interview.

- A. Self-explanatory
- B. Self-explanatory
- C. List names of persons who lived in these counties during 1951-62.
- D. Ask present age of each individual. If it is known that a person is over 40, but exact age is unknown, record ">40".
(Note: A person who will become 40 years of age during 1982 shall be deemed eligible for the survey.)
- E. Ask only of or on behalf of persons eligible on the basis of residence history and age. Assign log numbers in numerical sequence at time of interview. Use first and last initials of interviewer as a prefix. (e.g. The third interview conducted by Loraine Woodbury would have the log number LW3.)

SURVEY FORM

1-4. These items are to be recorded by the interviewer.

- 1. Observe and check proper answer.
- 2. Transcribe from RESPONDENT IDENTIFICATION FORM.
- 3. Record log number.
- 4. Pertains to present residence. Record prior to interview.

Questions: Stress to respondent that answers are to be relative to principal residence during the period 1951-1962, inclusive.

- 1. Purpose - Location of residence affected radiation dose.
- 2. Purpose - Radiation dose dependent upon length of time in area.

Note: Question refers only to time interval 1951-62, inclusive.

- 3. Purpose - External radiation dose from fallout on the ground dependent upon shielding provided by construction materials.

4. Purpose - External radiation dose dependent on occupancy of basement area.
5. Purpose - External radiation dose dependent on occupancy of second or third stories or attic area.
- 6.-8. Purpose - Occupation and time spent out-of-doors affects external dose from fallout.
9. Purpose - Amount of radioactivity ingested with water dependent on source of water.
10. Purpose - Amount of radioactivity in milk dependent on source of milk and location and feeding habits of cows.

Note: "Your own cow" refers to "family or close neighbor's cow." Do not check "yes" if milk primarily purchased from a commercial dairy or store.

11. Purpose - Fresh, leafy vegetables are efficient collectors of radioactive fallout. The harvest and dates of harvest of leafy vegetables affects the ingestion of radioactivity.

Note: "Leafy vegetables" includes items such as lettuce, spinach, chard, beet greens.

12. Purpose - Source of milk for infants affects internal radiation dose to the infant.

Note: Consider "infant" to be less than one year old or still nursing or on-bottle.

13. Purpose - To establish quantities and primary sources of foods consumed. These data are directly applicable to the estimation of internal radiation dose resulting from ingestion of contaminated foods.

Notes:(1) Do not press respondents too hard for answers. Many will remember quantities, etc. We would rather have a blank response than a wild guess.

(2) Under item b. relating to quantities consumed, mark "___" if person is quite uncertain. Any units can be used, depending on which are familiar to respondent (e.g. glasses per day, pounds per week, portions per month, etc.).

(3) If you have serious doubts about the validity of these answers, make a note to this effect on the form after the interview.

Notes:(4) Item 5 also includes cereals.

(5) Item (13) refers to local game fish.

(6) For many of these answers, products may be locally produced at some times of the year and not others. Estimate percentage, if possible.

14. Purpose - To determine if respondent qualifies to be asked subsequent questions relating to agricultural practices.

Notes:(1) Many people lived in town, but operated a farm or ranch.

(2) Someone who lived on a farm or ranch but did not have direct involvement in its operation would not qualify for continuation of the interview.

(3) "Farm" is defined as in the United States Census of Agriculture, 1950. "Places of 3 or more acres were counted as farms if the value of agricultural products raised on them in 1954, exclusive of home gardens, amounted to \$150 or more. The agricultural products could have been either for home use or sale. Places of less than 3 acres were counted as farms only if the value of sales of agricultural products in 1954 amounted to \$150 or more." From Household Food Consumption Survey 1955, USDA.

15. Purpose - To determine the nature of the farm or ranch (e.g. what things were produced).

Note: Livestock includes any animals such as beef, pork, sheep, poultry, etc.

16. Purpose - Alfalfa is a major livestock feed and is a main pathway of radionuclide transport.

17. Purpose - Cutting dates and destination of alfalfa are critical pieces of information that affect the structure of the simulation model.

Note: Mark "____" in space if answer is not known.

18. Self-explanatory

19. Purpose - To develop information on commercial crops, their culture methods, and usage. Plowing blends radioactive surface deposits into the soil, hence the questions on plowing. Harvest date affects the radionuclide content of the crop. Shipment and use patterns affect the distribution of the fallout contamination.

Notes:(1) In item f., "locally" means within the county.

(2) Mark "____" in space if answer is not known.

20. & 21. Self-explanatory

22. Purpose - Several radionuclides accumulate in animal products such as meat and milk. The quantities of radioactivity in animal products depend on animal feeding patterns and sources of feed.

Notes:(1) From-To questions refer to calendar dates (e.g. early June through September).

(2) Mark "—" if answer is not known.

(3) Fill in NA in some blanks.

23. Self-explanatory

24. Purpose - The quantity of radioactivity in meat fluctuates through time, depending on numerous factors. Therefore, slaughter dates are an important determinant of radionuclide concentrations in meat. The usage pattern of animal products affects the dose to humans in the area of concern.

Note: Mark "—" if answer is not known.

25. Self-explanatory

APPENDIX C

REPORT ON

**SURVEY OF LIFE-STYLES, FOOD HABITS,
AND AGRICULTURAL PRACTICES IN
WASHINGTON AND IRON COUNTIES,
UTAH AND LINCOLN COUNTY,
NEVADA FOR THE YEARS 1951-1962.**

BY

**H. LORAIN WOODBURY
DIXIE COLLEGE
ST. GEORGE, UTAH**

SEPTEMBER 1982

REPORT ON
SURVEY OF LIFE-STYLES, FOOD HABITS, AND AGRICULTURE PRACTICES
IN WASHINGTON AND IRON COUNTIES, UTAH AND LINCOLN COUNTY, NEVADA

For the Years 1951-1962

INTRODUCTION

In the spring of 1980 Dr. F. Ward Whicker of Colorado State University contacted Dixie College for the purpose of arranging a survey of life styles of residents in the Southern Utah and Nevada area. Arrangements were made for H. Loraine Woodbury to serve as the principal investigator. A contract was signed June 1, 1980. The contract included a statement of work which stated:

"Dixie College, with H. Loraine Woodbury as Principal Investigator, will conduct a survey of qualified residents of St. George, Hurricane, Cedar City, and Parowan, Utah, and Caliente and Pioche, Nevada--to develop an information data base on life styles, food habits, and agricultural practices in these communities."

Results of the survey shall form the basis of a report that will be due at a date yet to be specified and mutually agreeable to CSU and DC. The report shall include: (1) a summary of the procedures used for the survey, including dates and places of the interviews and names and addresses of the interviewers; (2) a tabulated summary of the survey results, broken down by counties and types of communities within counties; (3) a summary of extraneous notes obtained during the survey; and (4) an appendix containing all individual forms (DP-467) completed during the survey."

Subsequent to this statement, changes were made to include all of Iron and Washington County in Utah, and all of Lincoln County in Nevada.

PROCEDURES

During the summer of 1980, a preliminary interview instrument was developed and a list of long-time residents was compiled for the people who lived in the St. George, Cedar City, Utah and Caliente-Pioche, Nevada area. The original intent was to interview every accessible long-term resident of the three areas with the estimation of one thousand potential interviewees. The list contained over 1700 homes with two qualified residents in many homes.

The form was submitted to the Department of Energy (DOE), along with the suggested method of sampling. Approval did not arrive during the summer months,

however, some preliminary contact was made with a number of residents to test the acceptability of the interview instrument.

Ninety-Four people were interviewed in the St. George area, 81 in the Cedar City area, and 31 in the Panaca-Pioche area. The information gathered from these interviews was used in helping to revise the questionnaire.

The Washington office of DOE did not accept the method of sampling, nor the instrument at that time. But, with suggestions from that office and with the aid of DOE people in the Nevada Operations Office in Las Vegas, a procedure and form was approved during the late fall of 1980. The procedure was as follows:

First: Every house in the three counties had to be located on a map, which was accomplished by driving on practically every street and road in the three counties. Most of this was done during December 1980 and early January 1981. Once the maps were created they were then sent to Dr. Forest Miller of the Desert Research Institute in Las Vegas, Nevada, where they were delineated ten houses to a group, then each group was given a number. Using acceptable random sampling methods--approximately 20% of the groups were selected for interviews. With the assistance of students, people in all houses in the selected groups were contacted, with the exceptions of those homes in which no one responded during at least three visits. It is noted that in a few homes two qualified residents were interviewed and counted separately.

In addition to the groups of homes contacted in the cities and towns, attempts were made to contact all rural farm houses. Arbitrarily less than ten houses in a group, was considered rural.

These interviews were carried out during June through December 1981, by upper classmen students. To qualify as a respondent or interviewee, the person must have lived in one or more of the counties during the interval 1951-1962.

The attached Respondent Identification Form DP-467 was used for these interviews. The completed interview forms were duplicated, the originals being sent to Dr. Forest Miller of the DRI for computer analysis. The duplicate forms were stored in the office of H. L. Woodbury, at Dixie College.

SUMMARY OF CONTACTS AND INTERVIEWS

Total houses existing in the three counties are as such:

Washington County	7,750
Iron County	4,570
Lincoln County	<u>1,290</u>
Total	13,610

The goal was to contact approximately 20% of the total houses in each county. The number contacted were:

Washington County	1,358
Iron County	745
Lincoln County	<u>307</u>
Total	2,410

People qualified for interviews not living on farm or ranch:

Washington County	196
Iron County	121
Lincoln County	<u>47</u>
Total	364

People qualified for interview living on Farm or Ranch:

Washington County	68
Iron County	59
Lincoln County	<u>32</u>
Total	149

Total of all interviews:

Washington County	264
Iron County	180
Lincoln County	<u>79</u>
Total	523

Total houses contacted in three counties:

Washington County	1,622	(21% of houses)
Iron County	925	(20% of houses)
Lincoln County	<u>385</u>	(29% of houses)
Total	2,933	

PEOPLE WHO ASSISTED WITH THE PROJECT

Summer 1980:

Rebecca Gull (Mrs. Kenneth Gull), 503 N. Sunset Dr., St. George, UT 84770
Robert Larson, 390 S. 1100 W., Cedar City, UT 84720
Paul Christensen, Box 154, Panaca, NV 89042
Mark Woodbury, 344 N. 400 W., St. George, UT 84770
H. L. Woodbury, 344 N. 400 W., St. George, UT 84770

June through December 1981:

Martin Alan Abbinanti, 3304 N. Southport, Chicago, IL 60657
Joan Clarke, Cannonville, UT 84718
Mark Woodbury, 344 N. 400 W., St. George, UT 84770
H. L. Woodbury, 344 N. 400 W., St. George, UT 84770

NUMBER OF HOURS EXPENDED BY EACH INTERVIEWER

Summer 1980:

Robert Larson	175 hours
Rebecca Gull	125 hours
H.L. Woodbury	108 hours
Paul Christensen	22 hours
Mark Woodbury	14 hours
Total	<u>444</u>

June through December 1981:

Martin Abbinanti	575 hours
Joan Clarke	977 hours
H.L. Woodbury	268 hours
Mark Woodbury	42
Total	<u>1862</u>

Grand Total Hours 2,306

EXPENDITURES FOR MANHOURS

\$ 3,840	Summer 1980 - first contract period (6-1-80 thru 9-30-80)
\$11,497	Summer & Fall 1981 - 2nd contract period (10-1-80 through 9-30-81)
<u>\$ 1,835</u>	Fall 1981 - 3rd contract period (10-1-1981 through 9-30-1982)
\$17,172	TOTAL

MILEAGE COSTS

1,361 miles traveled (June through sept. 1980) for cost of	266.01
17,253 miles traveled (Oct. 1, 1980 - Sep. 30, 1981) for cost of	\$2,886.01
<u>6,054 miles traveled (Oct. 1, 1981 - Dec. 30, 1981) for cost of</u>	<u>\$1,331.88</u>
24,668 miles	TOTAL \$4,483.90

WAGES AND MILEAGE TOTAL \$21,655.90

Other Costs paid to Dixie College:

Current Expenses, employee benefits and overhead costs \$4700.10

Total cost of project \$26,356.00

APPENDIX D

SUMMARIES OF DATA FROM THE SURVEY OF LIFESTYLES, FOOD HABITS, AND AGRICULTURAL PRACTICES

SUMMARIES PROVIDED BY

**CAROL B. THOMPSON
DESERT RESEARCH INSTITUTE
LAS VEGAS, NEVADA**

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**AREA COVERED
BY THE
LIFESTYLE SURVEY**

D1

APPENDIX D1

APPENDIX D2

Sex of Respondents

10 County Survey

Category	Number	Percent
Male	349	38.4
Female	560	61.5
NR	1	0.1
Total Responses	910	

NR = no response

Age Distribution (Yr) of Respondents

10 County Survey

Category	Number	Percent
38 - 45	59	6.5
46 - 55	160	17.6
56 - 65	249	27.4
66 - 75	210	23.1
76 - 85	135	14.8
86 - 93	28	3.1
> 40*	69	7.5
NR	1	0.1
Total Responses	910	

NR = no response

*did not give specific age

Community Type

10 County Survey

Category	Number	Percent
Community	813	89.3
Open Range	91	10.0
Indian Reservation	6	0.7
Total Responses	910	

APPENDIX D3

Current County of Residence

10 County Survey

Category	Number	Percent
Coconino, AZ	9	1.0
Mojave, AZ	18	2.0
Clark, NV	66	7.3
Esmeralda, NV	12	1.3
Lincoln, NV	79	8.7
Nye, NV	55	6.0
White Pine, NV	159	17.5
Iron, UT	170	18.7
Kane, UT	79	8.7
Washington, UT	263	28.9
NR	0	0
Total Responses	910	

NR = no response

County of Residence 1951 - 1962

10 County Survey

Category	Number	Percent
Coconino, AZ	8	0.9
Mojave, AZ	16	1.8
Clark, NV	58	6.4
Esmeralda, NV	12	1.3
Lincoln, NV	82	9.0
Nye, NV	57	6.3
White Pine, NV	148	16.3
Iron, UT	173	19.0
Kane, UT	69	7.6
Washington, UT	286	31.4
NR	1	0.1
Total Responses	910	

NR = no response

APPENDIX D4

Respondents with Own Milk Cow

10 County Survey

Category	Number	Percent
Yes	467	51.3
No	442	48.6
NR	1	0.1
Total Responses	910	

NR = no response

Respondents with Own Milk Cow

3 County Survey

Category	Number	Percent
Yes	298	55.1
No	243	44.9
Total Responses	541	

Respondents Who Grew Own Leafy Vegetables

10 County Survey

Category	Number	Percent
Yes	573	63.0
No	336	36.9
NR	1	0.1
Total Responses	910	

NR = no response

APPENDIX D5

Respondents Who Grew Own Leafy Vegetables

3 County Survey

Category	Number	Percent
Yes	352	65.1
No	189	34.9
Total Responses	541	

Respondents with Infants in House 1951 - 1962

10 County Survey

Category	Number	Percent
Yes	411	45.2
No	496	54.5
NR	3	0.3
Total Responses	910	

NR = no response

Respondents with Infants in House 1951 - 1962

3 County Survey

Category	Number	Percent
Yes	244	45.1
No	294	54.3
NR	3	0.6
Total Responses	541	

NR = no response

APPENDIX D6

Principal Source of Milk for Infants 1951 - 1962

10 County Survey

Category	Number	Percent
Breast (1)	89	21.7
Fresh Cow (2)	58	14.1
Formula, Canned (3)	158	38.4
Goat	3	0.7
Breast + Fresh	25	6.1
1 + 2 + 3	13	3.2
Breast + Canned	39	9.5
Breast + Goat	3	0.7
Canned + Fresh	13	3.2
Soybean	2	0.5
Dairy	2	0.5
Fresh + Powdered	1	0.2
Canned + Soybean	1	0.2
Don't Know	2	0.5
NR	2	0.5
Total Responses	910	

NR = no response

APPENDIX D7

Principal Source of Milk for Infants 1951 - 1962

3 County Survey

Category	Number	Percent
Breast (1)	57	23.4
Fresh Cow (2)	51	20.9
Formula, Canned (3)	81	33.2
Goat	1	0.4
Breast + Fresh	15	6.2
1 + 2 + 3	7	2.9
Breast + Canned	23	9.4
Breast + Goat	2	0.8
Canned + Fresh	6	2.5
Soybean	0	0.0
Dairy	0	0.0
Fresh + Powdered	0	0.0
Canned + Soybean	0	0.0
Don't Know	0	0.0
NR	1	0.4
Total Responses	244	

NR = no response

APPENDIX D8

Infant Milk Source Where Own Milk Cow Was Kept 1951 - 1962

10 County Survey

Category	Number	Percent
Breast (1)	46	19.8
Fresh Cow (2)	37	15.9
Formula, Canned (3)	73	31.5
Goat	2	0.9
Breast + Fresh	21	9.1
1 + 2 + 3	12	5.2
Breast + Canned	31	13.4
Breast + Goat	1	0.4
Canned + Fresh	6	2.6
Soybean	0	0.0
Dairy	0	0.0
Fresh + Powdered	0	0.0
Canned + Soybean	0	0.0
Don't Know	2	0.9
NR	1	0.4
Total Responses	232	

NR = no response

APPENDIX D9

Infant Milk Source Where No Milk Cow Was Kept 1951 - 1962

10 County Survey

Category	Number	Percent
Breast (1)	43	24.0
Fresh Cow (2)	21	11.7
Formula, Canned (3)	85	47.5
Goat	1	0.6
Breast + Fresh	4	2.2
1 + 2 + 3	1	0.6
Breast + Canned	8	4.5
Breast + Goat	2	1.1
Canned + Fresh	7	3.9
Soybean	2	1.1
Dairy	2	1.1
Fresh + Powdered	1	0.6
Canned + Soybean	1	0.6
Don't Know	0	0.0
NR	1	0.6
Total Responses	179	

NR = no response

APPENDIX D10

Comparison of Average Daily Intake of Milk (ml/day) Rupp^a vs. ORERP-10 County Survey

Age		RUPP	ORERP
1-11 Then	Average	542	484
	Standard Deviation		306
	# Responses		42
12-18 Then	Average	485	514
	Standard Deviation		378
	# Responses		84
19+ Then	Average	261	452
	Standard Deviation		384
	# Responses		699
40+ Now ^c	Average		462
	Standard Deviation		402
	# Responses		67
TOTAL ^b	Average		459
	Standard Deviation		381
	# Responses		897

^aRupp, 1980, Table 8

^bIncludes 5 nonrespondents for age/sex

^cAge at time of survey

APPENDIX D11

Comparison of Average Daily Intake of Eggs (g/day) Rupp^a vs. ORERP-10 County Survey

Age		RUPP	ORERP
1-11 Then			
	Average	25	52
	Standard Deviation		27
	# Responses		42
12-18 Then			
	Average	31	56
	Standard Deviation		48
	# Responses		84
19+ Then			
	Average	41	57
	Standard Deviation		41
	# Responses		700
40+ Now ^c			
	Average		56
	Standard Deviation		32
	# Responses		68
TOTAL ^b			
	Average		56
	Standard Deviation		40
	# Responses		899

^aRupp, 1980, Table 8

^bIncludes 5 nonrespondents for age/sex

^cAge at time of survey

APPENDIX D12

Comparison of Average Daily Intake of Leafy Vegetables (g/day) Rupp^a vs. ORERP-10 County Survey

Age		RUPP	ORERP
1-11 Then			
	Average	20	27
	Standard Deviation		21
	# Responses		39
12-18 Then			
	Average	30	25
	Standard Deviation		19
	# Responses		82
19+ Then			
	Average	50	29
	Standard Deviation		19
	# Responses		668
40+ Now ^c			
	Average		27
	Standard Deviation		21
	# Responses		68
TOTAL ^b			
	Average		28
	Standard Deviation		19
	# Responses		861

^aRupp, 1980, Table 8

^bIncludes 5 nonrespondents for age/sex

^cAge at time of survey

APPENDIX D13

Comparison of Average Daily Intake of Poultry (g/day) Rupp^a vs. ORERP-10 County Survey

Age		RUPP	ORERP
1-11 Then			
	Average	18	49
	Standard Deviation		41
	# Responses		42
12-18 Then			
	Average	27	37
	Standard Deviation		35
	# Responses		81
19+ Then			
	Average	26	44
	Standard Deviation		41
	# Responses		681
40+ Now ^c			
	Average		65
	Standard Deviation		45
	# Responses		67
TOTAL ^b			
	Average		45
	Standard Deviation		41
	# Responses		876

^aRupp, 1980, Table 8

^bIncludes 5 nonrespondents for age/sex

^cAge at time of survey

APPENDIX D14

Comparison of Average Daily Intake of Meats (g/day) Rupp^a vs. ORERP-10 County Survey

Age		RUPP ^b	ORERP ^c
1-11 Then			
	Average	118	172
	Standard Deviation		131
	# Responses		42
12-18 Then			
	Average	197	124
	Standard Deviation		86
	# Responses		84
19+ Then			
	Average	232	146
	Standard Deviation		114
	# Responses		692
40+ Now ^d			
	Average		173
	Standard Deviation		124
	# Responses		68
TOTAL ^e			
	Average		147
	Standard Deviation		113
	# Responses		891

^aRupp, 1980, Table 8

^bBeef, pork, other & mixtures

^cBeef, pork, lamb

^dAge at time of survey

^eIncludes 5 nonrespondents for age/sex

APPENDIX D15

Comparison of Average Daily Intake of Cheese, Ice Cream, & Breads (g/day) Rupp^a vs. ORERP-10 County Survey

	RUPP	ORERP
Cheese		
Average	28.9	35.0
Standard Deviation		41
# Responses		760
Ice Cream		
Average	123.3	44.8
Standard Deviation		52
# Responses		889
Breads		
Average	67.2	75.3
Standard Deviation		40
# Responses		896

^aRupp, 1980, Table 9

APPENDIX D16

Beginning Date for Cow on Pasture
Respondents with Own Milk Cow

10 County Survey

Category	Number	Percent
January	1	0.2
February	0	0.0
March	9	1.9
April	31	6.6
May	104	22.3
June	26	5.6
July	0	0.0
August	0	0.0
September	0	0.0
October	2	0.4
November	0	0.0
December	0	0.0
NR	211	45.2
YR	83	17.8
Total Responses	467	

NR = no response

YR = year round

APPENDIX D17

Ending Date for Cow on Pasture Respondents with Own Milk Cow

10 County Survey

Category	Number	Percent
January	0	0.0
February	0	0.0
March	0	0.0
April	2	0.4
May	1	0.2
June	1	0.2
July	3	0.6
August	3	0.6
September	93	19.9
October	52	11.1
November	16	3.4
December	2	0.4
NR	211	45.2
YR	83	17.8
Total Responses	467	

NR = no response

YR = year round

APPENDIX D18

Beginning Date for Vegetable Harvest Respondents Growing Own Leafy Vegetables

10 County Survey

Category	Number	Percent
January	2	0.3
February	1	0.2
March	8	1.4
April	13	2.3
May	86	15.0
June	147	25.7
July	177	30.9
August	89	15.5
September	34	5.9
October	6	1.0
November	0	0.0
December	0	0.0
NR	8	1.4
YR	2	0.3
Total Responses	579	

NR = no response

YR = year round

APPENDIX D19

Ending Date for Vegetable Harvest Respondents Growing Own Leafy Vegetables

10 County Survey

Category	Number	Percent
January	0	0.0
February	0	0.0
March	0	0.0
April	3	0.5
May	8	1.4
June	5	0.9
July	22	3.8
August	87	15.2
September	306	53.4
October	105	18.3
November	18	3.1
December	4	0.7
NR	13	2.3
YR	2	0.3
Total Responses	573	

NR = no response

YR = year round

APPENDIX E

CONCLUSIONS OF THE BIOMOVs REPORT ON THE RELATIVE IMPORTANCE OF INGESTION FOR MULTIPLE PATHWAY DOSE ASSESSMENTS

CONCLUSIONS

Lessons from the Case Studies and Screening Criteria

- Ingestion pathways are significant and often dominant contributors to dose for many release scenarios and radionuclides.
- Ingestion pathways can usually be ignored in dose assessments when ingestion by man of water, soil or food originating from the contaminated area is precluded. Ingestion pathways can usually also be ignored in the case of inert gases.
- The relative contributions of the various radiation exposure pathways to total dose cannot be stated generically because they depend on:
 - The release scenario
 - The radionuclide (and its chemical form)
 - Ecological characteristics of the area
 - Timing of the release (season, year)
 - Human behavior and environmental management
 - The dose calculated (organ or effective)
 - Time over which the dose is calculated
 - The target group or population
 - Choice of model and parameter values
 - The assessment question
- If contaminated water is directly consumed by people, it may be a dominant pathway for total dose, especially for radionuclides that tend to remain in solution. However, if fish living in the same water are also consumed by people, this pathway is likely to dominate for radionuclides that have reasonably high bioaccumulation factors.

- A broad variety of foods, as well as water, tend to be important pathways for strontium isotopes under a variety of release scenarios.
- External exposure pathways tend to dominate total doses for relatively insoluble gamma-emitting radionuclides, particularly when the materials accumulate in soils and beach sediments and human occupancy is high.
- Total doses from gamma emitters with chemical properties similar to those of nutrient elements (e.g. ^{137}Cs , ^{60}Co), may be dominated by external exposures or by ingestion, depending on the nature and human use of the area.
- Inhalation is frequently a dominant pathway for actinides such as ^{232}Th and ^{239}Pu because of their limited transport across biological membranes, but high inhalation dose factors.
- When inhalation pathways are precluded, ingestion pathways for actinides (food, water, soil) may contribute significantly to total dose. In these cases, doses from radioactive daughter products may be important.
- The case studies support the notion that uncertainty associated with the main pathways contributing to total dose also produces most of the uncertainty in total dose.
- The various case studies were generally consistent with one another, and with expectation from other experience, in regard to the importance rankings of exposure pathways. In cases where they were not consistent, logical reasons for the differences were usually evident.

- Assuming unit release of radionuclides for assessment purposes allows comparison between the different radionuclides and determination of their relative significance. However, for real situations their impact will also depend on the radionuclide inventory.

Working Paradigms Concerning Uncertainty

Based upon results of the case studies, as well as other experience of BIOMOVs participants, some relevant concepts concerning uncertainty were developed. These will be stated as "working paradigms" that can perhaps be expected to be modified as additional information becomes available. The following working paradigms are proposed:

- Uncertainty has two components: Natural variability and ignorance. With sufficient sampling and research, it possible to better-estimate and understand the components of natural variability. It is possible to reduce ignorance through research.
- Uncertainties in the dominant pathways will normally have the greatest influence on the uncertainty in the total dose from all pathways. This may not be true in cases where a sub-dominant, but not insignificant, pathway is much more uncertain than the dominant pathway.
- Uncertainties of parameters and processes affect the total uncertainty of a prediction according to (a) the relative functional importance of the parameter or process, and (b) the magnitude of the uncertainty in the parameter or process.

- In multiplicative chains, the relative uncertainty of the result tends to be higher than that of individual factors and to increase with the number of factors in the chain, provided the factors are not correlated. A preponderance of strong negative correlations among factors, however, will reduce the relative uncertainty of some individual terms.
- In additive models without correlated terms, the relative uncertainty (i.e. coefficient of variation or geometric standard deviation) of the sum will decrease with the number of terms and will be less than the relative uncertainty of some individual terms.
- The magnitude of absolute uncertainty (standard deviation or variance) of a parameter tends to increase in proportion to the mean of the parameter.

Deficiencies in the Knowledge Base

The results of the case studies and discussions from the various BIOMOVs meeting have uncovered a number of deficiencies in the base of information. Some of these are listed below:

- Very few studies have carefully treated the question of accuracy and uncertainty in each parameter necessary to calculate dose or risk from all relevant pathways.
- Relatively few studies have used state-of-the-art techniques to propagate uncertainty in their models.
- Very little effort has been made to validate models against human body burdens, which integrate over all intake pathways and steps in the foodchain. This holds for expected values as well as uncertainties.

- There is little theoretical basis from which to extrapolate from well-studied ecosystems and contamination scenarios to other ecosystems and scenarios. Thus, there is still a great need for site-specific data. A better scientific basis is needed to predict across the n -dimensional arrays of release scenarios, sites, contaminants, etc.
- Little effort has been made to use uncertainty-sensitivity analysis techniques to guide research and funding priorities in the areas of dose and risk assessment. These techniques quantify and rank the important contributors to the uncertainty in dose and risk prediction. As a result, research is not currently reducing uncertainties very effectively.